INCH-POUND

MIL-HDBK-225A
25 March 1991

Superseding
MIL-HDBK-225(AS)
4 October 1968

MILITARY HANDBOOK

SYNCHROS

DESCRIPTION AND OPERATION

DEPARTMENT OF DEFENSE • UNITED STATES OF AMERICA

AMSC - N/A

FSC 5990

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

DEPARTMENT OF THE NAVY
Washington, DC 20361

Synchros
Description and Operation

1. This military handbook is approved for use by all Departments and Agencies of the Department of Defense and supersedes MIL-HDBK-225(AS) dated 4 October 1968.

2. This handbook has been prepared for use by engineers, designers and technicians and is intended to serve as a guide and not as a catalog of military synchros. Other documents are available which describe each synchro type fully and in detail. The information contained in this manuscript applies equally well to commercial synchro types.

3. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commanding Officer, Naval Air Engineering Center, Engineering Specifications and Standards Department, Code 53, Lakehurst, NJ 08733-5100, by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

FOREWORD

The need for synchros became apparent when work was to be done at a location remotely situated from its control station. The original mechanical system of shafts, gears, belts and pulleys was impractical in these situations. The major types or classes of synchros developed to fill these needs are: torque synchros, control synchros, induction potentiometers (linear synchro transmitters), and resolvers. This latter type may be considered as a separate entity; therefore, MIL-HDBK-218 has been prepared to cover their description and applications. It is sufficient to say that a resolver is a precision synchro used for coordinate transformation, resolution of vectors into components, and conversion of rectangular to polar coordinates. Encoders have been developed to convert analog functions into digital language for input into digital computing devices. However, synchros continue to be used wherever analog computers or computations are desirable.

Applications shown are merely representations. The mounting methods and accessories described have been developed after long periods of research. They have passed the time-proven test of service in the field.

The text of this handbook has been prepared with no reference made to specific synchros. The reader is directed to the Department of Defense Index of Specifications and Standards (DODISS) for information relating to either the General Specification covering synchros, MIL-S-20708, or its associated specification sheets. The preferred types of synchros are listed in the latest issue of MIL-STD-710.

The following aspects of synchros are described herein:

a. Basic principles underlying synchro design
b. Construction
c. Characteristics of the various types
d. Applications
e. Synchro accessories
f. Method of mounting
g. Standard connections
h. Zeroing techniques
i. Troubleshooting
j. Miscellaneous

Each type or class of synchro will be covered in detail, but first, properties and characteristics common to all types will be discussed. Some basic principles of electricity and magnetism will also be reviewed.

TABLE OF CONTENTS

Para.	Title	Page
1.0	SCOPE	1
1.1	Purpose	1
1.2	Scope	1
1.3	Classification	1
1.4	Basic principles	2
2.0	REFERENCED DOCUMENTS	7
2.1	Government documents	7
2.2	Order of precedence	8
2.3	Source of documents	8
3.0	DEFINITIONS	8
3.1	Definition of synchro and synchro systems	8
3.1.1	Synchros	8
3.1.1.1	Torque transmitter	8
3.1.1.2	Control transmitter	9
3.1.1.3	Torque differential transmitter	9
3.1.1.4	Control differential transmitter	9
3.1.1.5	Torque receiver	9
3.1.1.6	Torque differential receiver	9
3.1.1.7	Control transformer	9
3.1.2	Synchro system	9
3.1.2.1	Torque system	9
3.1.2.2	Control system	9
3.2	Synchro terminology	10
3.2.1	Rotor angular displacement	10
3.2.1.1	Rotor position	10
3.2.1.2	Rotor angle	10
3.2.1.3	Direction of rotation	10
3.2.1.4	Angular displacement	10
3.2.1.5	Electrical zero	10
3.2.1.6	Increasing reading	10
3.3	Definition of servo	10
3.4	Servo terminology	10
3.4.1	Open-cycle control	10
3.4.2	Closed-cycle control	10
3.4.3	Continuous control	11
3.4.4	Deviation	11
3.4.5	Error signal	11
3.4.6	Instrument and power servos	11

TABLE OF CONTENTS - Continued

Para. Title Page

4.0 GENERAL SYNCHRO CONSTRUCTION AND CHARACTERISTICS. . 11

4.1 General 11
4.2 Rotor construction 11
4.3 Stator construction 12
4.4 Lamination stacking 12
4.5 Unit assembly 12
4.6 Transmitters 13
4.7 Receivers 13
4.8 Double receivers 14
4.9 Differential units 14
4.10 Control transformers 15
4.11 Units with rotatable stator 16
4.12 Comparison of 60-Hz and 400-Hz synchros 16
4.13 Synchro characteristics 16
4.14 Speed of synchro units and systems 20
4.15 Synchro capacitors 22

5.0 LOAD LIMITS FOR MIL-S-20708 SYNCHROS 25

5.1 Load limits for MIL-S-20708 synchros in torque systems 25
5.2 Load limits for MIL-S-20708 synchros mixed systems 30
5.3 Load limits for MIL-S-20708 synchros in control systems 32

6.0 SYNCHROS IN ACTION 37

6.1 Synchro systems 37
6.2 Torque synchro systems 37
6.3 Control synchro systems 47
6.4 Servo systems using synchros 51

7.0 MILITARY SYNCHRO TYPES 54

7.1 Designation codes 54
7.2 Military specifications and standards for synchros 55

8.0 HARDWARE, TOOLS, AND MOUNTING METHODS 56

8.1 General 56
8.2 Hardware for standard units 56
8.3 Tools for standard synchros 57
8.4 Methods for mounting standard synchros 57
8.5 Methods for mounting pre-standard synchros. 58
8.6 Mounting gears and dials on synchros 59

TABLE OF CONTENTS - Continued

Para.	Title	Page
9.0	STANDARD CONNECTIONS FOR SYNCHROS	60
9.1	The need for standard connections	60
9.2	Example of an increasing reading	60
9.3	Standard wire designations	60
9.4	Two-speed systems	60
9.5	Standard voltages	61
9.6	Standard transmitter connections	61
9.7	Standard receiver connections	61
9.8	Standard connections for differential transmitters	61
9.9	Standard connections for differential receivers	61
9.10	Standard connections for control transformers	61
9.11	Standard connections for synchro capacitors	61
9.12	Standard connections for servo amplifiers	61
9.13	Standard connections for servomotors	62
9.14	Standard connections that apply to a typical servomotor	62
10.0	ZEROING SYNCHROS	62
10.1	The need for electrical zero	62
10.2	Electrical zero conditions	63
10.3	Zeroing procedures	64
10.4	Summary	69
11.0	SYNCHRO TROUBLES	69
11.1	Handling	69
11.2	Maintenance	69
11.3	Troubleshooting synchro systems	69
11.4	Oscillations and spinning in torque systems	73
12.0	SIMILAR DEVICES	74
12.1	Clarification	74
12.2	Interior communication (IC) units	74
12.3	Commutator transmitter	80
12.4	Stepping motor system	80
12.5	DC position indicator	81

TABLE OF CONTENTS - Continued

TABLES

Table	Title	Page
I	Synchro functional classifications	82
II	Standard capacitor boxes	83
III	Special types of capacitor boxes	83
IV	Characteristics of standard synchro capacitors . .	84
V	Limiting loads for MIL-S-20708 Synchros in 400-Hz Torque System A	85
VI	Limiting loads for MIL-S-20708 Synchros in 400-Hz Torque System B	86
VII	Limiting loads for MIL-S-20708 Synchros in 400-Hz Torque System C	87
VIII	Optimum values of synchro capacitors for MIL-S-20708 400-Hz synchro CDX-CT units	89
IX	Limiting CT loads, additional to torque loads of Table V, for MIL-S-20708 Synchros in 400-Hz Mixed System A	90
X	Limiting CT loads, additional to torque loads of Tables VI and VII, for MIL-S-20708 Synchros in 400-Hz Mixed System B	90
XI	Limiting CDX-CT loads that replace a TDX-TR branch of Tables VI and VII for MIL-S-20708 Synchros in 400-Hz Mixed System C.	91
XII	Limiting loads for MIL-S-20708 Synchros in 400-Hz Control System A	92
XIII	Limiting loads for MIL-S-20708 Synchros in 400-Hz Control System B	93
XIV	Limiting loads for MIL-S-20708 Synchros in 400-Hz Control System C	95
XV	Limiting loads for MIL-S-20708 Synchros in 60-Hz Torque System A	99
XVI	Limiting loads for MIL-S-20708 Synchros in 60-Hz Torque System B	99
XVII	Limiting loads for MIL-S-20708 Synchros in 60-Hz Torque System C	100
XVIII	Optimum values of synchro capacitors for MIL-S-20708, 60-Hz, CDX-CT units	101
XIX	Limiting CT loads, additional to torque loads of Tables XV, for MIL-S-20708 Synchros in 60-Hz Mixed System A	101
XX	Limiting CT loads, additional to torque loads of Tables XVI and XVII, for MIL-S-20708 synchros in 60-Hz Mixed System B	102

TABLE OF CONTENTS - Continued

TABLES - Continued

Table	Title	Page
XXI	Limiting CDX-CT loads that replace a TDX-TR branch of Tables XVI and XVII for MIL-S-20708 Synchros in 60-Hz Mixed System C	102
XXII	Limiting loads for MIL-S-20708 Synchros in 60-Hz Control System A	103
XXIII	Limiting loads for MIL-S-20708 Synchros in 60-Hz Control System B	103
XXIV	Limiting loads for MIL-S-20708 Synchros in 60-Hz Control System C	104
XXV	Size of pre-standard type synchros	106
XXVI	Function of pre-standard type synchros	106
XXVII	MIL-S-20708 QPL Synchros	107
XXVIII	MIL-S-20708 Non-QPL Synchros	120
XXIX	Pre-standard synchros of MIL-S-2335.	128
XXX	General trouble symptoms	131
XXXI	Open or shorted rotor	132
XXXII	Shorted stator	133
XXXIII	Open stator	134
XXXIV	Wrong stator connections, rotor wiring correct	135
XXXV	Wrong stator and/or reversed rotor connections	136
XXXVI	Size 5 units	137
XXXVII	Size 1 transmitters	138
XXXVIII	Size 6 transmitters	139

TABLE OF CONTENTS - Continued

FIGURES

Figure	Title	Page
1	Schematic symbols used to show external connections	140
2	Schematic symbols for relative positions of windings	140
3	Simple torque system	141
4	Simple control system	141
5	Bar magnet and its field	142
6	Magnetic attraction	142
7	Magnetic repulsion	142
8	Three magnets acting as one	143
9	Molecular arrangement	143
10	Magnetic field around conductor	143
11	Magnetic field around coil	144
12	Positioning bar magnet with one electromagnet .	144
13	Positioning bar magnet with two electromagnets.	145
14	Positioning bar magnet with two electromagnets of different strength	145
15	Positioning bar magnet with two electromagnets of variable strength	146
16	Bar magnet with three electromagnets	146
17	Positioning bar magnet with three electromagnets by applying voltage between one coil and the other two	146
18	Positioning bar magnet with three electromagnets by applying voltage between two of the three coils	147
19	Positioning bar magnet with three electromagnets with fixed voltage applied to two coils and variable voltage applied to the third	147
20	Electromagnet replaces bar magnet	147
21	Phase relationships	148
22	Basic transformer	148
23	Transformation ratio	148
24	Transformer with rotatable primary	149
25	Transformer with one primary winding and three secondary windings	149
26	Cutaway view of typical synchros	150
27	Salient pole rotor	151
28	Magnetic polarity variations in salient pole rotor	151
29	Drum or wound rotor	151
30	Typical stator	152

TABLE OF CONTENTS - Continued

FIGURES - Continued

Figure	Title	Page
31	Stator lamination	152
32	Cutaway view of synchro transmitter or receiver	152
33	Stator voltage vs rotor position	153
34	Terminal-to-terminal voltages	154
35	Phantom view of typical synchro differential	155
36	Phantom view of typical control transformer	155
37	Control transformer with rotatable stator	156
38	Torque	156
39	Measuring unit torque gradient	157
40	Estimating actual torque gradient	157
41	Control transformer output voltage	158
42	Current effect drawn by coil	158
43	Coil currents	159
44	Power factor	159
45	Effect of capacitor on coil currents	160
46	Control transformer stator windings	160
47	Control synchro system (CX-CT)	160
48	Control transformer stator windings with capacitors	161
49	Delta-connected capacitors	161
50	Control synchro system with synchro capacitor	161
51	TX-TDX-TR system without synchro capacitor	162
52	TX-TDX-TR system with synchro capacitor	162
53	TX-TDX-CT system without synchro capacitor	162
54	Use of synchro capacitors in TX-TDX-CT system	163
55	Location of synchro capacitor in TX-TDX-CT system	163
56	TX-TR system without synchro capacitors	163
57	TX-TR system with synchro capacitor across rotor leads	164
58	Connections and current values of capacitors in Table IV	164
59	System designation key for torque systems	165
60	System designation key for control systems	166
61	External connections of a transmitter-receiver system	166
62	Internal conditions in TX-TR system with rotors in correspondence	167
63	Internal conditions in TX-TR system with rotors not in correspondence	167
64	Magnetic polarities at a particular instant with TX rotor at 30° and TR rotor at 0°	167

TABLE OF CONTENTS - Continued

FIGURES - Continued

Figure	Title	Page
65	Internal conditions in TX-TR system with TX rotor at 120° and TR rotor at 60°	168
66	Magnetic polarities at a particular instant with TX rotor at 120° and TR rotor at 60° . . .	168
67	Effect of reversing S1 and S3 connections between TX and TR	169
68	Effect of rotor position difference on maximum stator current	169
69	Effect of actual rotor position on individual stator current	170
70	Effect of rotor position difference on rotor current	171
71	Internal conditions in TX-TR system when TX and TR rotors are 180° apart	171
72	Magnetic polarities at a particular instant when TX and TR rotors are 180° apart	172
73	Position of TDX stator field when TX rotor is at 0°	172
74	Rotating TDX stator field by turning the TX rotor	172
75	Subtraction with TDX	173
76	Magnetic field positions in TX-TDX-TR system with all rotors at 0°	173
77	Effect of turning TX rotor in TX-TDX-TR system connected for subtraction	173
78	Effect of turning TDX rotor in TX-TDX-TR system connected for subtraction	174
79	Effect of turning TDX rotor clockwise in a TX-TDX-TR system connected for subtraction . .	174
80	Addition with TDX	174
81	Effect of turning TX rotor in TX-TDX-TR system connected for addition	175
82	Effect of turning TDX rotor in TX-TDX-TR system connected for addition	175
83	Subtraction with TDR	175
84	Effect of turning both TX rotors in TX-TDR-TX system connected for subtraction	176
85	Addition with TDR	176
86	Effect of turning both TX rotors in TX-TDR-TX system connected for addition	176

TABLE OF CONTENTS - Continued

FIGURES - Continued

Figure	Title	Page
87	Standard connections for differentials	177
88	Conditions in CX-CT system with rotors in correspondence	177
89	Conditions in CX-CT system with CX rotor at 0° and CT rotor at 90°	178
90	Conditions in CX-CT system with CX rotor at 180° and CT rotor at 90°	178
91	Typical position servo	178
92	Standard synchro sizes; approximately one-half actual size	179
93	Pre-standard synchro sizes; approximately one-half actual size	180
94	Mounting clamp assembly	181
95	Clamping discs - MS90400	181
96	Adapter assemblies - MS90401	181
97	Zeroing rings - MS90398	181
98	Shaft nuts - MS17187	181
99	Drive washers - MS17186	182
100	Straight pinion wrench - MS90393	182
101	90-degree pinion wrench - MS90394	182
102	Socket wrench assemblies - MS90395	182
103	Mounting a synchro using a machine screw . . .	183
104	Mounting a synchro using a clamping disc assembly	183
105	Mounting a synchro using an adapter assembly (from the shaft end)	183
106	Mounting a synchro using an adapter assembly (from the terminal board end)	184
107	Mounting a synchro using three mounting clamp assemblies	184
108	Mounting a synchro using a zeroing ring	184
109	Flange-mounted synchro	185
110	Type 5N nozzle-mounted synchro	185
111	End view of nozzle-mounted synchro	185
112	Bearing-mounted synchro	186
113	Mounting a gear on a standard synchro (exploded view)	186
114	Mounting a gear on a standard synchro (assembled cutaway view)	187
115	Mounting a dial on a standard synchro	187
116	Correct positioning of drive washer to insure maximum loading (cross section)	187
117	Mounting gears or dials on earlier synchros . .	188

TABLE OF CONTENTS - Continued

FIGURES - Continued

Figure	Title	Page
118	Mounting dials on a 2R double receiver	189
119	Example of an increasing reading	190
120	Standard wire designations	190
121	Connections on a typical two-speed system . . .	190
122	Standard voltages	191
123	Standard transmitter connections	192
124	Standard receiver connections	192
125	Standard connections for differential transmitters	193
126	Standard connections for differential receivers	193
127	Standard connections for control transformers .	194
128	Standard connections for control transformers to servo amplifier	194
129	Standard connections for synchro capacitors . .	195
130	Standard connections for servo amplifiers . . .	195
131	Standard connections for shunt field DC servomotor	196
132	Standard connections for split series field, commentator type, AC or DC servomotor	196
133	Standard connections for two-field induction servomotors	197
134	Standard connections that apply to a typical servomotor	197
135	Schematic diagram of autotransformer	198
136	Coarse electrical zero markings on synchro units	198
137	Zeroing a TX or CX using a voltmeter	198
138	Zeroing a TX using a TR	199
139	Zeroing a TR with a free rotor	199
140	Zeroing torque receiver by electrical lock . .	199
141	Zeroing a differential transmitter using a voltmeter	200
142	Zeroing a TDX using a TX and TR	200
143	Zeroing a TDR with free rotor	200
144	Zeroing a TDR using two zeroed TX's	201
145	Zeroing a CT using a voltmeter	201
146	Overload indicator in TX-TR system	201
147	Determining when overload indicator will light	202
148	Simple blown fuse indicator	202
149	Blown fuse indicator requiring only one lamp .	202
150	Blown fuse lights overload indicator	203
151	Other equipment in parallel with synchros . . .	203
152	Voltage balance check	203
153	60-hertz Synchro Tester Mk 33 Mod 0	204

TABLE OF CONTENTS - Continued

FIGURES - Continued

Figure	Title	Page
154	Close-up view of dial and index on 60-hertz Synchro Tester Mk 33 Mod 0	204
155	400-hertz Synchro Tester Mk 30 All Mods	205
156	Close-up view of dial on 400-hertz Synchro Tester Mk 30 All Mods	205
157	Switching oscillations	206
158	IC unit schematic diagrams	207
159	IC unit shaft rotation	207
160	Zeroing an IC unit	208
161	Commutator transmitter	208
162	Stepping motor system	209
163	Stepping motor	209
164	Stepping motor in various positions	210
165	Typical stepping motor showing terminals . . .	210
166	Stepping motor to synchro converter	211
167	DC position indicator	211
	INDEX	212

MILITARY HANDBOOK

SYNCHROS
DESCRIPTION AND OPERATION

This handbook is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Purpose. This handbook is intended as a guide for use by military personnel concerned with the use, interchangeability, maintenance and repair of synchros, and the design of weapons systems.

1.2 Scope. This handbook contains the physical and functional descriptions of synchros.

1.3 Classification. Synchros have been developed to satisfy various needs and are classified in several broad categories according to their intended function, as listed in Table I. The input, output and military abbreviations of each type are also included in Table I. Brief definitions of each category are given in section 3. More complete descriptions are provided in section 4.

1.3.1 Synchros. Synchros resemble small electric motors. Electrically, they are transformers whose primary-to-secondary coupling can be varied by physically rotating one winding inside the other.

1.3.1.1 Symbols. In this publication, synchros are represented schematically by the symbols shown on Figures 1 and 2. The symbols on Figure 1 are used when it is necessary to show only the external connections to a synchro, and the symbols on Figure 2 are used when it is important to understand the physical relationships between the rotor and stator. The small arrow on the rotor indicates the angular displacement of the rotor.

1.3.2 Synchro systems. Synchro systems consist of two or more interconnected synchros, plus auxiliary units such as synchro capacitors and trouble indicators where required.

1.3.2.1 Two types of synchro systems. Systems which provide a low-power mechanical output sufficient to position indicating devices, actuate sensitive switches, or move light loads without power amplification are known as torque systems (see Figure 3). With such a system, accuracy in the order of one degree is attainable. On the other hand, where large torques or high accuracy are required, control type synchros are used. In these systems, a voltage is transmitted for conversion to torque through an amplifier and a servomotor, as shown on Figure 4. Control systems provide an electrical output and are widely used as follow-up links and error detectors in servo, automatic control, systems. Quite often, one system will perform both torque and control functions. Individual units are designed for use in either torque or control systems. Some torque units may be used as control units, but control units cannot replace torque units.

1.4 Basic principles.

1.4.1 Magnetism. A brief review of the principles of magnetism is included here because synchros are electromagnetic devices.

1.4.1.1 Magnet types. A magnet is a body which has the power of attracting iron, steel, cobalt, nickel and certain other metals. One form of iron oxide, called magnetite, exists as a magnet in its natural state. This natural magnet was first known as lodestone, or leading stone, because of its directional property. When suspended and free to move, a magnet will assume a nearly north-south position. Bodies made magnetic by some process are called artificial magnets. Artificial magnets possess the same power of attraction and directional property as natural magnets. In the balance of these discussions, reference to a magnet is intended to mean an artificial magnet. A permanent magnet is one which retains its magnetism over a long period of time, while a temporary magnet quickly loses its magnetism when the magnetizing force is removed. Surrounding a magnet is an area in which its attracting power exists. Theoretically, this area, called a magnetic field, is infinite; but the field is usually apparent only in the close vicinity of the magnet. Magnets come in many shapes, but one of the most common is the bar magnet (see Figure 5).

1.4.1.2 Poles. The end regions of a magnet are known as poles. The end pointing toward geographic north is called the north-seeking or simply the north pole, and the other is called the south-seeking or south pole. On Figure 5 the broken lines represent the lines of force which make up the magnetic field. These lines of force are directional, radiating from the north pole of the magnet, passing through the surrounding medium, and re-entering the magnet at the south pole. Field strength is greatest near the poles, where the lines of force are more concentrated.

1.4.1.3 Magnetic attraction and repulsion. If two magnets are close enough, their fields interact and the magnets, when free to move, change position. If the lines of force, and hence the fields, are in the same direction, they tend to combine and pull the magnets together. Figure 6 shows two bar magnets with unlike poles close together, with the resultant attraction. Figure 7 shows the bar magnets placed with like poles close together. The lines of force are now in opposite directions, and the fields repel each other, pushing the magnets apart. The strength of attraction or repulsion (1) increases as the pole strengths increase, (2) decreases as the distance between the poles increases, and (3) depends on the medium through which the lines of force pass. A magnetic field passes more easily through some materials than others. Permeability is the measurement of ease with which a substance passes a magnetic field, as compared to its ease of passage through air or a vacuum. If the lines of force encounter more resistance (magnetic opposition) in passage through a material than in passage through air, the material is referred to as diamagnetic. Materials more magnetizable than air are called paramagnetic. Such diamagnetic materials as tin, gold, copper, silver, zinc and lead are actually slightly repelled by a magnet. Paramagnetic materials are attracted slightly, except the class known as ferromagnetic (iron alloys, nickel, and cobalt) which a magnet attracts strongly.

1.4.1.4 Interacting magnetic fields. Two or more interacting magnetic fields produce one resultant field. Figure 8 shows three magnets with interacting fields and the single field produced.

1.4.1.5 Molecular arrangement. In an unmagnetized body, the molecules (actually tiny magnets themselves) are not aligned in any particular manner with respect to each other. By stroking an unmagnetized piece of iron or steel with a magnet several times in the same direction, the molecules are arranged so that the piece of iron or steel becomes magnetized. Figure 9 shows the molecular arrangement before and after magnetization. A body may be magnetized without actually being touched by a magnet. Magnetism produced without physical contact is called "induced magnetism".

1.4.2 Electromagnetism. In any electrical circuit, the flow of current through a conductor produces a magnetic field around that conductor. Figure 10 illustrates the right-hand rule for determining the direction of the magnetic field produced. The thumb indicates the direction of current flow and the fingers indicate the direction of the field. If the conductor is coiled, the lines of force combine and the coiled wire becomes a magnet. Figure 11 shows such a coil, commonly called a solenoid. Here the magnetic polarity is determined by grasping the coil in the right hand so that the fingers indicate the direction of current flow. The thumb then points to the north pole of the coil's field.

1.4.2.1 Strength of an electromagnet. With a soft iron core inserted inside the coil, the lines of force become more concentrated and the solenoid becomes an electromagnet. A magnetic field exists only while current flows through the coil; if the current flow is reversed in direction, the magnetic polarity also reverses. The strength of an electromagnet depends upon the number of turns of wire in the coil and the quantity of current flowing. Above a saturation point, no increase in either the number of wire turns or the current flow will increase the strength of an electromagnet with a given core.

1.4.3 Positioning a permanent magnet with electromagnets. First consider a permanent bar magnet mounted on a pivot near an electromagnet, as on Figure 12. When the electromagnet is not energized, the bar magnet is free to turn. With a voltage applied to the electromagnet, the bar magnet assumes a position dependent on the polarity of the electromagnet. A given pole of the electromagnet attracts the unlike pole of the bar magnet. The bar magnet turns on the pivot to align itself so that its south pole is nearest the north pole of the electromagnet. If the electromagnet reverses polarity, the bar magnet will again pivot, placing the north pole nearest the electromagnet.

1.4.3.1 Using two electromagnets. Figure 13 shows two electromagnets placed at right angles to each other near the pivoted bar magnet. As the polarity of the applied voltage changes, the bar magnet assumes the indicated positions. On Figure 13(A), the side electromagnet is not energized, and the top one has maximum effect on the bar magnet. On Figure 13(B), both electromagnets have equal effects. On Figure 13(C), the polarity of the voltage applied to the side electromagnet has changed, and the position of the bar magnet has changed accordingly. On Figure 13(D), the top electromagnet is de-energized, and the left-hand electromagnet has full effect. If the supply voltage to one of the electromagnets is made variable, so that its strength may be increased or decreased, it is possible to position the bar magnet at angles other than the 45-degree intervals shown on Figure 13. Figure 14 shows a lesser voltage applied to the top electromagnet, allowing the side electromagnet to have more effect. This positions the bar magnet at some intermediate angle which, in this case, is 300 degrees. If the strength of each electromagnet is made independently variable as on Figure 15, the bar magnet can be made to assume any angular position through 360 degrees.

1.4.3.2 Using three electromagnets. For the closest approach so far to actual synchro operation, consider three electromagnets connected as shown on Figure 16. If a voltage is applied between one coil and the other two, the bar magnet assumes one of the positions shown on Figure 17. The bar magnet can also be positioned by applying a voltage between any two of the three coils as shown on Figure 18. If a fixed voltage is applied between two coils, and a variable voltage to the third, as on Figure 19, the bar magnet assumes some position between 0 and 60 degrees, depending on the relative voltage amplitudes. Applying the proper combination of voltages to the three coils turns the bar magnet to any desired position.

1.4.3.3 Using AC instead of DC. In all previous examples, DC voltages have been applied to the electromagnets. Since synchros operate on AC rather than DC, consider what happens if AC is applied to an electromagnet. In standard military synchros, the frequency of the AC is usually either 60 or 400 hertz. During one cycle, the voltage amplitude goes from zero to maximum positive, back to zero, then to maximum negative, and finally back to zero.

1.4.3.3.1 Polarity. Since the polarity reverses twice during one cycle, the number of times the magnetic polarity reverses each second will be twice the excitation frequency. With an AC voltage applied to a coil, as in an electromagnet, the current does not reverse at exactly the same time as the voltage; however, to simplify following discussions, it is assumed that it does. Since the polarity of an electromagnet depends on the direction of electron flow, the bar magnet is attracted in one direction during one half-cycle and in the other direction during the next half-cycle. Because of its inertia, the bar magnet cannot turn rapidly enough to follow the changing magnetic field.

1.4.3.3.2 Using electromagnets. If the bar magnet is replaced with an electromagnet, the same results are accomplished as when DC was used previously. On Figures 20(A) and 20(B), the voltages applied to both coils are reversed at the same time, so that the magnetic fields (direction indicated by arrows) reverse at the same time; under these conditions, the electromagnets are mutually attracted. On Figure 20(C), the connections to the coils are reversed; the lower magnet would turn if it were free to do so. The lower magnet is free to turn on Figure 20(D) and positions itself so that the magnetic fields are all in the same direction.

1.4.4 Phase relationships. In considering two or more AC quantities, voltage or current, it is sometimes necessary to compare instantaneous polarities. If one voltage is positive or negative in respect to a reference voltage (usually zero), it means nothing unless the specific time is stated when that condition exists. For purposes of this discussion, it is necessary to compare only two AC voltages. If the voltages vary so that both are maximum positive at the same time and both maximum negative at the same time, they are referred to as being in phase. If one of the two voltages is maximum positive when the other is maximum negative, they are opposite in phase or 180 degrees out of phase. Figure 21 illustrates the relative phases of three AC voltages. The arrows indicate relative phase.

1.4.4.1 Effective value. There are other phase relationships as well as in phase and 180 degrees out of phase, but they are not discussed here because the AC voltages in synchros are either in phase or 180 degrees out of phase with each other. The meters shown on Figure 21 indicate an apparently constant voltage rather than the actual variations shown in the graphs. Like the bar magnet, the meter cannot follow the rapid changes in polarity. It is common practice to calibrate AC voltmeters to read the effective value (the value of AC voltage which produces the same heating effect as a same value constant DC voltage), although some meters are calibrated to read peak values. Only effective values are treated in these discussions.

* NOTE *

> A synchro is not a three-phase device. In three-phase devices, the three voltages are equal in amplitude, but 120 degrees apart in phase.

1.4.5 Transformer theory. An AC source connected to a coil causes the magnetic field around the coil to fluctuate. A second coil placed in the vicinity of the energized coil has an AC voltage induced in it. Two or more coils so arranged form a simple transformer as shown on Figure 22. The energized winding is referred to as the primary, and the winding in which the voltage is induced is referred to as the secondary. The voltage induced in the secondary is dependent upon the transformation ratio, the voltage applied to the primary, and the physical orientation of the coils.

1.4.5.1 Transformation ratio and applied voltage. The ratio of the secondary voltage to the primary voltage is called the transformation ratio. Figure 23 shows a transformer with a 25-turn secondary and a 50-turn primary. In a perfect transformer, this 1-to-2 ratio would provide an equal transformer ratio (0.5) and the secondary voltage would be 57.5 volts. Losses inherent in all transformers require that the secondary-to-primary turns ratio be greater than the transformation ratio. If the transformation ratio and primary voltage are known, multiply one by the other to obtain the secondary voltage. As an example, if a transformer with a 115-volt primary has a transformation ratio of 0.78, the secondary voltage is approximately 90 volts.

1.4.5.2 Physical position of the coils. With the primary and secondary coils positioned so that their axes are parallel, maximum linkage exists, and the induced voltage is maximum. The induced secondary voltage will decrease if the angle between the primary and secondary axes is changed from zero degrees. On Figure 24, the primary is pivoted and the secondary is stationary. As the primary is turned, the secondary voltage changes. On Figure 24(A), the voltage from C to D is maximum and in phase with the voltage from A to B. At 45 degrees (Figure 24(B)) the voltage is reduced. With the coils at right angles (Figure 24(C)), no voltage is induced. As the coils pass the 90-degree relationship (Figures 24(D) and 24(E)), the flux linkages are reversed and the voltage from C to D is 180 degrees out of phase with the voltage from A to B. The graph (Figure 24(F)) shows how the voltage and phase relationships change as the primary is rotated. The secondary could be turned and the same effect produced. Regardless of which winding rotates, or if both rotate, the angle between the windings determines the induced voltage.

1.4.5.2.1 Example of one primary coil and three secondary coils. Consider a transformer with one primary coil and three secondary coils connected as shown on Figure 25. When AC is applied to the primary, the voltages induced in each secondary coil depend upon the position of that coil in respect to the primary. If the primary is made rotatable, it may effectively be considered a synchro transmitter. The actual principles of operation for all synchros are covered in subsequent paragraphs.

1.4.5.3 Operating frequency.

*** CAUTION ***

Transformers and synchros are designed for use on a specific frequency and should **never** be operated on other frequencies because serious damage may result.

The rate at which the field fluctuates is determined by the frequency of the applied AC, and a different rate of change causes a change in the induced voltage due to changes in losses. If two transformers of equal power-handling capacity are designed to operate on different frequencies, the one designed for the higher frequency may be made the physically smaller of the two. There are rare applications whereby 400 hz synchro transmitters do supply control transformers designed for 60 hz.

2. REFERENCED DOCUMENTS

2.1 Government documents.

2.1.1 Specifications and standards. The following specifications and standards form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, specified in the solicitation.

SPECIFICATIONS

MILITARY

MIL-S-20708	Synchros, General Specification For
MIL-S-81746	Servtorqs, General Specification For

(See Supplement 1 of MIL-S-20708E for list of applicable specification sheets.)

STANDARDS

MILITARY

MIL-STD-710	Synchros, 60 and 400 Hertz
MS17183	Clamp Assembly (Synchro)
MS17186	Washer, Drive (Synchro)
MS17187	Nut, Plain, Hexagon
MS35275	Screw, Machine-Drilled Fillister Head, Slotted, Corrosion-Resisting Steel, Passivated, UNC-2A
MS35276	Screw, Machine-Drilled Fillister Head, Slotted, Corrosion-Resisting Steel, Passivated, UNF-2A
MS35338	Washer, Lock-Spring, Helical, Regular (Medium) Series
MS90393	Straight Pinion Wrench

STANDARDS

MILITARY

MS90394	Pinion Wrench, 90°
MS90395	Socket Wrench
MS90398	Zeroing Rings
MS90400	Clamping Discs
MS90401	Adapter Assemblies

2.2 Order of precedence. In the event of a conflict between the text of this standard and the references cited herein (except for associated detail specifications, specification sheets or MS standards), the text of this standard shall take precedence.

2.3 Source of documents.

2.3.1 Government specifications and standards. Copies of the referenced military specifications and standards are available from the Standardization Documents Order Desk, Bldg. 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094. For specific acquisition functions, these documents should be obtained from the contracting activity or as directed by the contracting activity.

3. DEFINITIONS

3.1 Definitions of synchros and synchro system types.

3.1.1 Synchros. Synchros are basically transformers in which the coupling between the primary and secondary windings may be varied. This is accomplished by designing the windings in the form of a stator and rotor, respectively, of a motor-like device. Figure 26 is a cutaway view of typical synchros. This definition may be expanded to state that a synchro is an electromechanical device which provides a physical measure of shaft position as the result of an electrical input; or conversely, gives an electrical output which is a function of the angular position of its shaft.

3.1.1.1 Torque transmitter. A torque transmitter is a unit which electrically transmits angular information according to the physical position of its rotor with respect to its stator. The rotor position is determined mechanically or manually by the information to be transmitted. The end result is the transformation of angular data into corresponding electrical values. Torque transmitters are normally connected to other torque synchros (receivers, differential receivers, or differential transmitters). Under certain conditions, they may be used as control transmitters.

3.1.1.2 Control transmitter. Except for being connected only to control transformers or control differential transmitters, control transmitters perform the same function as torque transmitters.

3.1.1.3 Torque differential transmitter. A torque differential transmitter electrically transmits angular information equal to the algebraic sum or difference of the electrical input supplied to its stator from a torque transmitter and the angular position of its rotor with respect to its stator. The rotor is positioned to modify or correct the data from the torque transmitter by some desired amount. The electrical output of this unit will be applied to a torque receiver, another torque differential transmitter, or a torque differential receiver.

3.1.1.4 Control differential transmitter. This is functionally the same as the torque differential transmitter except that it is used in control rather than torque systems.

3.1.1.5 Torque receiver. A unit whose rotor assumes an angular position determined by the electrical input supplied to its stator from a torque transmitter or torque differential transmitter. For proper operation, the rotor must be connected in parallel with the rotor of the associated torque transmitter, and both synchros energized from the same power source.

3.1.1.6 Torque differential receiver. A unit whose rotor assumes a physical position determined by the algebraic sum or difference of the electrical inputs supplied from two torque transmitters, two torque differential transmitters, or one torque transmitter and one torque differential transmitter.

3.1.1.7 Control transformer. A unit which, when supplied with electrical information from a transmitter or differential transmitter, produces an electrical output proportional to the sine of the difference between the control transformer rotor angle and the angle represented by the electrical input.

3.1.2 Synchro system. A synchro system is a circuit containing one or more synchros that operate on angular information and convey this information over a distance (see 6.1).

3.1.2.1 Torque synchro system. A torque synchro system is a system in which the transmitted signal does usable work.

3.1.2.2 Control synchro system. A control synchro system is a system in which the transmitted signal controls a source of power which does work.

3.2 Synchro terminology.

3.2.1 Rotor angular displacement.

3.2.1.1 Rotor position. In speaking of synchro units and systems, the rotor position is referred to as an angle of so many degrees, minutes, or seconds. Since it is not always stated to what respect this angle is measured, a few standard definitions are listed.

3.2.1.2 Rotor angle. The rotor angle of a practical synchro is the angular mechanical rotor displacement from the synchro zero position, measured in the positive direction, at which the synchro's output voltages exactly correspond to the output voltages of an ideal synchro set at any specific rotor position.

3.2.1.3 Direction of rotation. Direction of rotation, clockwise or counterclockwise, is determined while facing the emergent shaft end of the synchro. See section 9 for standard connections for synchros.

3.2.1.4 Angular displacement. Any deviation in the position of the movable winding (the rotor), with respect to the fixed winding (the stator), from a reference or zero position is called angular displacement.

3.2.1.5 Electrical zero. Electrical zero is the standard position to which all angular displacements are referred. In section 10, electrical zero is defined for various types of synchros.

3.2.1.6 Increasing reading. An increasing reading is being sent to a synchro when the numerical value of the information transmitted increases.

3.3 Servo system. A servo (short for servomotor) is a device used in servo systems that contains or delivers power to move a control. A servo system is an automatic control system which maintains a condition at or near a predetermined value.

3.4 Servo terminology. In addition to those already mentioned, a number of specialized terms are used in connection with servo systems. The more common of these are defined here:

3.4.1 Open-cycle control. Open-cycle control of a servo system means actuation of the servomotor solely by means of the input data, the feedback device being either removed or disabled. It should be clearly understood that any mechanism must include a feedback provision in order to be classified as a servo; but in testing certain servo characteristics, an open-cycle control is often useful. Under such conditions, the elements involved are frequently referred to as an open servo loop.

3.4.2 Closed-cycle control. Closed-cycle control refers to normal actuation of the system by the difference between input and output data, with the feedback device operative.

3.4.3 Continuous control. Continuous control is used to describe uninterrupted operation of the servo system on its load, regardless of the smallness of the error. All systems considered in this book exercise continuous control; however, there are systems which do not.

3.4.4 Deviation. The deviation or error of a servo is the difference between input and output.

3.4.5 Error signal. The error signal or error voltage is the corrective signal developed in the system by a difference between input and output.

3.4.6 Instrument and power servos. Instrument servos and power servos are designations used to classify servomechanisms according to their power output. An instrument servo is one rated at less than 100 watts maximum continuous output. A servomotor whose rating exceeds this amount is called a power servo.

4. GENERAL SYNCHRO CONSTRUCTION AND CHARACTERISTICS

4.1 General. A knowledge of unit construction and characteristics will provide a better understanding of synchro operation. As stated previously, synchros are, in effect, transformers whose primary-to-secondary coupling may be varied by physically changing the relative orientation of the two windings. This is accomplished by mounting one of the windings so that it is free to rotate inside the other. The inner movable winding is called the rotor; and the outer, usually stationary, winding is called the stator. The rotor consists of either one or three coils wound on sheet steel laminations. The stator normally consists of three coils wound in internally slotted laminations. In some units, the rotor is the primary and the stator is the secondary. In other units, the reverse is true.

4.2 Rotor construction. The laminations of the rotor core are stacked together and rigidly mounted on a shaft. Slip rings, mounted on and insulated from the shaft, terminate the ends of the coil or coils. Brushes riding on the slip rings provide electrical continuity during rotation and low-friction ball bearings permit the shaft to turn easily. In standard synchros, the bearings must permit rotation from very low speeds to speeds as high as 1200 rpm. The following is a description of two common type rotors.

4.2.1 Salient pole rotor. This type of rotor, shown on Figure 27, is frequently called a "dumbbell" or "H" rotor, because of the shape of its core laminations. The winding consists of a single machine-wound coil whose axis is perpendicular to the shaft. When used in transmitters and receivers, the rotor functions as the excitation or primary winding of the synchro. When energized, it becomes an electromagnet with the poles assuming opposite magnetic polarities. During one excitation cycle, the magnetic polarity changes as shown on Figure 28, and similar variations will occur in subsequent cycles. The graph indicates amplitude variations in the exciting current and the strength of the magnetic field resulting from that current.

4.2.2 Drum or wound rotors. Figure 29 shows a wound rotor, with two slip rings, used in most synchro control transformers, and in some torque transmitters. When used in differentials, three coils are wound so that their axes are displaced from each other by 120 degrees. One end of each coil terminates at one of three slip rings, while the other ends are connected together. Synchro windings of this type are called "Y-connected." A single coil of wire or a group of coils connected in series may be wound to produce either a concentrated winding effect, for use in control transformers, or the same distributed winding effect as that of the salient pole rotor, for use in torque transmitters.

4.3 Stator construction. The stator of a synchro is a cylindrical structure of slotted laminations on which three Y-connected coils are wound with their axes 120 degrees apart. Figure 30 shows a typical stator assembly and Figure 31 shows a stator lamination. Control transformer stators differ from those of other synchros mainly in that the control transformer winding consists of more turns of finer wire. Stators function as the primary windings in differentials and control transformers, and as the secondary windings in transmitters and receivers. Normally, stators are not connected directly to an AC source. Their excitation is supplied by the magnetic field of a rotor.

4.3.1 Slip rings. Some synchros are so constructed that both the stator and rotor may be turned. Connections to the stator are made via slip rings and brushes. In some units the slip rings are secured to the housing, and the brushes turn with the stator. In other units the brushes are fixed, and the slip rings are mounted on a flat insulated plate secured to the stator.

4.4 Lamination stacking. Stator and rotor laminations are stacked so that the slots formed are either parallel to the rotor shaft centerline or displaced so that the front end of a slot is in a straight line with the back end of the preceding slot. This displacement is called skew, and since the slot pitch is the angular distance between slot centers, the rotor or stator is said to be skewed one slot pitch. If the slots of both rotor and stator are parallel to the shaft centerline, the resultant flux concentrations of rotor and stator coils tend to make the rotor "slot-lock" in certain positions. Skewing changes the flux concentration enough to overcome this effect and its resultant angular errors. Either, but not both, rotor or stator laminations may be skewed.

4.5 Unit assembly. The rotor is mounted so that it may turn within the stator. A cylindrical frame houses the assembled synchro. Standard synchros have an insulated terminal block secured to one end of the housing at which the internal connections to the rotor and stator terminate, and to which external connections are made. Pre-standard and special synchro types often have pigtail leads brought out from inside the unit, rather than terminals.

4.6 Transmitters. The conventional synchro transmitter, shown on Figure 32, uses a salient pole rotor and a stator with skewed slots. When an AC excitation voltage is applied to the rotor, the resultant current produces a magnetic field as shown on Figure 28. The lines of force, or flux, vary continually in amplitude and direction and, by transformer action, induce voltages in the stator coils. The effective voltage induced in any stator coil depends upon the angular position of that coil's axis with respect to the rotor axis. When the maximum coil voltage is known, the voltage induced at any angular displacement can be determined. Figure 33 shows the voltage induced in one stator coil as the rotor is turned to different positions. The rotor excitation is 115 volts and the maximum coil voltage is 52 volts.

4.6.1 Terminal-to-terminal stator voltages. Because the common connection between the stator coils is not accessible, it is possible to measure only the terminal-to-terminal voltages. When the maximum terminal-to-terminal voltage is known, the terminal-to-terminal voltages for any displacement can be determined. Figure 34 shows how these voltages vary as the rotor is turned. Values are above the line when the terminal-to-terminal voltage is in phase with the R1 to R2 voltage, and below the line when the voltage is 180 degrees out of phase with the R1 to R2 voltage. As an example, when the rotor is turned 50 degrees from the reference position, the S1 to S3 voltage will be about 70 volts and in phase with the R1 to R2 voltage; the S3 to S2 voltage will be about 16 volts also in phase with the R1 to R2 voltage; and the S2 to S1 voltage will be about 85 volts, 180 degrees out of phase with the R1 to R2 voltage. Although the curves on Figure 34 resemble time graphs of AC voltages, they show only the variations in effective voltage amplitude and phase as a function of the rotor position. In a time graph, the horizontal axis would show the time rather than rotor position.

4.7 Receivers. Torque receivers, usually called receivers, are electrically identical to torque transmitters of the same size. In some sizes of standard synchros, units are designated as torque receivers, but may be used as either transmitters or receivers. These units are called torque receiver-transmitters.

4.7.1 Rotor movement. Normally the receiver is unrestrained except for brush and bearing friction. When power is first applied to a system, the transmitter position quickly changes; or if the receiver is switched into the system, the receiver rotor turns to correspond to the position of the transmitter rotor. This sudden motion can cause the rotor to oscillate (swing back and forth) around the synchronous position. Also, due to the similarity between synchros and single-phase induction motors, the rotor may spin if turned fast enough. Some method of preventing excessive oscillations or spinning must be used. In small units, a retarding action may be produced by a shorted winding on the quadrature axis, at right angles to the direct axis. In larger units, a mechanical device known as an inertia damper is more effective. Several variations of the inertia damper are in use. One of the more common types consists of a heavy brass flywheel which is free to rotate around a bushing attached to the rotor shaft. A tension spring on the bushing rubs against the flywheel causing them to turn together during normal operation. If the rotor shaft turns or tends to change its speed or direction of rotation suddenly, the inertia of the damper opposes the changing condition.

4.7.2 Stator voltages required to position rotor. Figure 34 shows both the voltages induced in the stator as a function of rotor position, and the voltages which must be applied to the stator to turn the rotor to a desired position.

4.8 Double receivers. There are certain applications when the readings on two indicator dials are to be compared or added. Follow-the-pointer and angle-reader dials in a Gun Director Train Indicator System are good examples of such usage.

4.8.1 Follow-the-pointer dials. In this type, two dials are mounted concentrically. When the indices on the inner and outer dials are aligned, the actual gun position and the gun train order are in agreement.

4.8.2 Angle-reader train dials. These dials are also concentric. The outer dial is driven by a receiver supplied with 1-speed data, and is graduated in 10-degree increments. The inner dial, driven by a receiver supplied with 36-speed data, is graduated in both degrees and minutes. The sum of the two dial readings is the actual gun position.

4.8.3 Type 2R double receiver. To reduce space requirements, a housing in which two receivers are mounted has been developed--the type 2R double receiver. The receiver used to drive the outer dial is nearest the shaft end. The receiver nearest the terminal board end drives the inner dial. The brush caps, mounted between the flanges, should not be removed because it is impossible to reinsert them properly without disassembling the unit.

4.9 Differential units. A mechanical differential connects three shafts together so that the rotation of any one shaft is either the sum of, or the difference between, the rotation of the other two. Synchro differentials are similar in operation. The results obtained by connecting differentials between other units of a system are covered in 6.2.2.1. Differentials operate either as transmitters--one electrical and one mechanical input produce one electrical output, or as receivers--two electrical inputs produce one mechanical output. In differentials, both rotor and stator windings consist of three Y-connected coils. Figure 35 is a cutaway view of a typical differential.

4.9.1 Differential transmitters. Differentials may be used as transmitters in either torque or control applications. In either use, the stator is normally the primary and receives its excitation from a torque or control transmitter, as appropriate. The voltages appearing across the rotor terminals are determined by the magnetic field produced by the stator currents and the physical position of the rotor. The magnetic field created by the stator currents assumes an angle corresponding to that of the magnetic field in the transmitter supplying the excitation. If the rotor position changes, the voltage present at the rotor terminals changes.

4.9.2 Differential receivers. As torque receivers are previously compared to torque transmitters, so may torque differential receivers be compared to torque differential transmitters. Both rotor and stator receive energizing currents from torque transmitters. The two resultant magnetic fields interact and the rotor turns. The position assumed by the rotor depends on how the differential is connected to the two transmitters. Paragraph 6.2.2.1 shows unit connections to obtain various indications.

4.9.3 Transformer action. It might appear that a differential's rotor and stator leads are interchangeable, but this is not usually true. In section 1, it is mentioned that the primary-to-secondary turns ratio determines the primary-to-secondary voltage ratio. The coils in differentials are wound so that when the axis of a rotor coil coincides with the axis of a stator coil, the voltage induced in the rotor coil equals the voltage across the stator coil. To provide this 1-to-1 voltage ratio after losses, the rotor must have more turns than the stator. If excitation is applied to the rotor of a differential transmitter, the voltage induced in the stator is less than the applied voltage. In differential receivers where both windings are energized, the differential stator should be connected to the transmitter having the higher secondary current rating. If the transmitters are identical, the stator should be connected to the closest transmitter to minimize the losses.

4.10 Control transformers. There is an ever-increasing tendency to use synchros as follow-up links in automatic control systems. Synchros alone do not possess sufficient torque (turning power) to rotate radar antennas or gun turrets; however, they can control power amplifying devices which can move these heavy loads. For such applications, a control transformer is used. Figure 36 is a phantom view of a typical control transformer (CT) with a drum rotor. The windings are effectively concentrated in the core center. Magnetizing current is supplied to the stator windings from either a transmitter (CX or TX), or differential transmitter (CDX or TDX). The magnetic field created by the stator currents corresponds in position to the position of the field in the synchro supplying the excitation. By transformer action, a voltage is induced in the rotor or secondary winding. The amplitude and phase of the induced voltage depends on the angular displacement of the CT rotor in respect to the CX, TX, CDX, or TDX rotor. When the two rotor positions correspond, the voltage across the CT rotor is minimum. The operation of these units is described further in 6.3.1.

4.11 Units with rotatable stator. When the particular system design permits, space can be saved and the loss of accuracy resulting from the use of an additional differential can be overcome by the use of a unit having a rotatable stator (see Figure 37). Except for the rotors used, a control transmitter, torque receiver, or control differential transmitter with both windings rotatable would be similar in construction. When a unit having a rotatable stator is used, the rotation of the stator provides the same modifying or correcting effect as that obtained by the insertion of a differential.

4.12 Comparison of 60-hertz and 400-hertz units. There are many ways in which synchros resemble transformers. If two transformers are to be made with identical power-handling capabilities, and one is to operate on 60 Hz and the other on 400 Hz, the one for use on 400 Hz will be physically smaller. The same can hold true for synchros. "Can" rather than "does" is used because some 400-hertz units are identical in size to their 60-hertz counterparts. This is done so that units can be physically interchanged without special mounting provisions. The reduction in physical size is due to: (1) the reduction in core size; less core area is required at higher frequency; (2) the number of primary turns; fewer turns are required at higher frequency; and (3) the number of secondary turns; reduced in proportion to reduction in number of primary turns.

4.13 Synchro characteristics.

4.13.1 Torque. Torque is simply a measure of how much load a machine can turn. In torque synchros, only small loads are turned; therefore, only a small amount of torque is required. Torque is expressed as the product of the force and the distance from the line of action to the center of rotation. In heavy machinery, torque may be expressed in pound-feet, but in synchros, torque measurements are in ounce-inches (oz-in). Consider the arrangement on Figure 38, where pulleys of different sizes are attached to a shaft. When the pulley radius is one inch, the torque required to lift the attached 6-ounce weight is 6 oz-in. When the pulley radius is two inches, the torque required to lift the same weight is 12 oz-in. Increasing the distance between the center of rotation and line of action increases the torque required.

4.13.1.1 Unit torque gradient. Unit torque gradient is the torque gradient of a synchro when it is connected to and energized from a duplicate locked unit. The curve on Figure 39 shows the unit torque gradient for a particular type of synchro. When this value is established as described below, it provides a measure of unit performance independent of how the synchro is used.

4.13.1.2 Plot description of Figure 39 curve. (1) Two torque receivers were connected in parallel with one rotor fixed in place and the other free to turn; (2) a special pulley was attached to the shaft of the unit under test and weights were suspended from the rim of the pulley;

(3) the weights turned the pulley and rotor shaft; (4) increasing the weight suspended increased the amount the shaft turned; (5) the amount of weight suspended and the corresponding shaft displacements were recorded and the curve was plotted. A portion of the curve is substantially linear and the slope of this linear portion is known as the torque gradient. Within the normal limits of displacement, up to about 10 or 20 degrees, the torque gradient (expressed in ounce-inches per degree) provides an easy way of determining the torque produced by the rotor shaft. For example, at a 10-degree displacement, the torque exerted is 10 times the unit torque gradient.

4.13.1.3 Actual torque gradient. Actual torque gradient is the torque gradient of a synchro measured when that synchro is used in a system. The actual torque gradient fcr any unit depends upon the number and type of units in a system.

4.13.1.4 Pull-out torque. Pull-out torque is the maximum torque which can be exerted by a synchro unit connected to and energized from a duplicate locked unit. Figure 39 shows that the torque increases with the rotor displacement and reaches a maximum at 90 degrees. The pull-out torque for this unit is 30 oz-in.

4.13.1.5 Stator force. The torque developed in a synchro results from the tendency of two magnets to align themselves. Since the rotor can be turned and the stator usually cannot, the stator must exert a force tending to pull the rotor into a position where the primary and secondary fields are in line. The strength of the field produced by the stator depends on the current through the stator coils. Current flow in the stator coils depends in turn upon the impedance of the coils. Since the current flow determines the magnetic field strength, and the field strength determines the torque, it follows that the unit torque gradient of a synchro is inversely proportional to the stator coil impedance.

4.13.1.6 Accuracy is affected by the torque gradient. In a system consisting of a transmitter driving a receiver, friction always causes the receiver rotor to lag slightly behind the transmitter rotor. A higher torque gradient means that a smaller lag produces enough torque to overcome this friction.

4.13.2 Torque transmitter load capacities. One transmitter may be used to drive a number of receivers connected in parallel, provided that the transmitter can supply the current necessary to operate all the receivers. If identical receivers are equally loaded, the approximate torque of each receiver can be determined by the formula:

$$Tr' = \frac{2R}{N + R} Tr$$

where

Tr' is the torque gradient of the receiver in the system

Tr is the unit torque gradient of the receiver

R is the torque gradient ratio $\frac{Tt}{Tr}$

Tt is the unit torque gradient of the transmitter

N is the number of identical receivers

4.13.2.1 Description of plot shown on Figure 40. Using this formula, a graph can be plotted which applies to any situation where a transmitter drives a number of equally loaded receivers. Figure 40 shows such a graph. Suppose that a number of type 15TR4A receivers are to be driven by a type 31TX4A transmitter. First, determine the ratio between the two unit torque gradients:

$$\frac{\text{31TX4A Unit Torque Gradient} \quad 0.67}{\text{15TR4A Unit Torque Gradient} \quad 0.17} = 4 \text{ (approx.)}$$

Then locate the ratio 4 along the bottom of the graph. Going up along the vertical line, curves for various numbers of receivers are crossed. If four receivers are operated from the transmitter, the actual torque gradient is equivalent to the unit torque gradient. If only two receivers are used, the actual torque gradient is 1.35 times the unit torque gradient. It is apparent from the graph that one of three conditions exists:

a. If the torque gradient ratio equals the number of receivers, the unit and actual torque gradients are equal.

b. If the torque gradient ratio exceeds the number of receivers, the actual torque gradient of the receivers exceeds the unit torque gradient.

c. If the torque gradient ratio is less than the number of receivers, the actual torque gradient is also less than the unit torque gradient.

4.13.2.2 Factors determining load capacity. The actual load capacity of any unit depends on several factors which cannot be readily summarized in tabular form. Increasing the load on a unit increases the current demand, resulting in a higher operating temperature. To determine accurately the load capacity, we must know the maximum permissible operating temperature of the driving unit, the quantity and type of driven units, and the mechanical loads upon the driven units.

4.13.3 Operating voltages. Standard synchros are designed for use on either 115 volts or 26 volts. The operating voltage is stated on the synchro nameplate.

4.13.4 Operating temperature. Standard synchros are required to sustain no damage while operating or standing in an ambient temperature of -55°C + 125°C. Pre-standard Navy synchros were required to operate between -25°C + 85°C. Early model standard synchros were designed and built to operate over the range -55°C to + 85°C. Qualified Products Lists (QPL's) were established to indicate the contractors who successfully met this and other criteria. The upper limit of the temperature range was expanded to +125°C to withstand the effects of high ambient temperatures encountered in aerospace applications. When a unit is energized, but not loaded, its temperature should not rise above certain specified limits.

4.13.5 Electrical error/static accuracy. For every physical position of a synchro rotor, there is a corresponding electrical position. Any difference between actual physical position and electrical position is known as electrical error. Sometimes the electrical error is called static accuracy. For differentials, the error is measured for both rotor and stator. This error is usually expressed as a maximum number of minutes. Sixty minutes equals one degree.

4.13.6 Receiver error. The difference between the position transmitted by a TX or TDX and the position assumed by a TR or TDR is known as receiver error. In measuring receiver error, the TR or TDR is connected to a transmitter, or transmitters, of equal size. This error is also expressed in minutes.

4.13.7 Synchronizing time. In a torque system, the position of the receiver rotor corresponding to that of the transmitter rotor is known as the synchronous position. The period of time required for a receiver or differential receiver to assume and hold the synchronous position is called the synchronizing time within one degree. The standard method of determining synchronizing time is to connect the unit under test, terminal-to-terminal, to an identical unit locked on electrical zero. Measurements are then taken of the time required for the test unit rotor to synchronize from displacements of 30 and 177 degrees ± 2°.

4.13.8 Operating speed. All standard synchros must be capable of operation at 1150 rpm continuously for 2000 hours without external axial load. Pre-standard Navy synchros are classed either as low speed or high speed. Low-speed units must be capable of operating continuously for 500 hours at 300 rpm. High-speed units must be capable of rotating at 1200 rpm continuously for 1500 hours.

4.13.9 Minimum voltage and fundamental component. If the rotor of a transmitter is at either 0 or 180 degrees, the S1-S3 terminal voltage theoretically will be zero (see Figure 34). This is based on the assumption that the unit is so constructed that the S1 and S3 windings are exactly identical and have equal and opposite voltages induced in them. Units this perfect are seldom found. Figure 34 also shows that the S1-S2 voltage is zero when the rotor is at 120 or 300 degrees, and that the S2-S3 voltage is zero when the rotor is at 60 or 240 degrees. These six null headings are obtainable in differentials and control transformers by shorting two stator leads together, applying 78 volts (10.2 volts for 26-volt synchros) between the two shorted terminals and the unshorted one, and reading the voltage across the rotor terminals. The null position depends on which two stator leads are shorted together. Although the null voltage seldom falls to zero, it must fall below certain specified values. The minimum voltage, as read on an electronic voltmeter, will be the sum of the fundamental component and its harmonics, multiples of excitation frequency. By using a filter, the harmonics can be eliminated and the fundamental component measured. This value also must fall below a specified maximum. The value of the null voltage is of major importance in control synchro systems where the system output is used to actuate a servo.

4.13.9.1 Null voltage of a control transformer. In a control system, the control transformer minimum output, or null position, is determined by the signal applied to its stator, and may occur at any heading. Section 5 contains additional information about the null voltage of a control transformer (see 5.3.1.4d and 5.3.1.5c.)

4.13.10 Control transformer voltage gradient. Figure 41 shows the output voltage of a control transformer. The slope of this curve from 0 to 10 degrees is called the voltage gradient and is expressed in volts-per-degree (v/deg).

4.14 Speed of synchro units and systems. Quite often synchros are referred to as 1-speed or 2-speed synchros, and a synchro system is referred to as a single-speed or dual-speed system. Since a 2-speed synchro is not the same as a dual-speed synchro system, these terms of reference are defined in an effort to avoid confusion.

4.14.1 Data transmission speeds. The gyro-compass aboard most naval vessels is located below deck near the center of gravity. Gyro-compass information, showing the ship's course, must be transmitted to various compass repeaters. In 1-speed data transmission, a synchro transmitter is geared to the gyro-compass so that one revolution of the rotor corresponds to one revolution of the gyro-compass. Further, in 36-speed data transmission, the transmitter rotor is geared to turn through 36 revolutions for one revolution of the gyro-compass. Simply, the speed of data transmission is the number of times a synchro transmitter rotor must turn to transmit a full range of values. Units transmitting data at one speed are frequently called 1-speed synchros. A unit transmitting data at 36-speed would be a 36-speed synchro, and so forth.

4.14.2 System speeds. It is quite common to transmit the same data at two different speeds. Referring again to the gyro-compass, on-ship's course data is commonly transmitted at 1-speed and 36-speed. A system where data is transmitted at two different speeds is called a dual- or double-speed system. Usually, a dual-speed system will be referred to by the speeds involved; for example, "1- and 36-speed system".

4.14.3 Summary. To summarize, the speed of data transmission is referred to as 1-speed, 2-speed, 36-speed or some definite numerical ratio. To indicate the number of speeds at which data is transmitted, speak of a single-speed or dual-speed transmission system.

4.14.4 Determining the speed to use. It is obvious that if data can be transmitted at different speeds, or if the same data is transferred at different speeds, there must be certain advantages and disadvantages to the various methods.

4.14.4.1 Single-speed system. If the data to be transmitted covers only a small range of values, a single-speed system is normally accurate enough. For example, if a device moves only 6 inches and the transmitter rotor which is geared to it turns through 360 degrees, a total error of one degree in the transmitter and the receiver to which it is connected causes an error of 0.01666 inch in the indicated position. For quantities without definite reference values, such as increasing range or bearing, a single-speed system may be made as accurate as desired. Greater accuracy is also possible by using higher speeds of data transmission, such as 36-speed. However, in such an arrangement, the self-synchronous feature of the 1-speed system is lost. Suppose that while the primary power to the system is interrupted, the transmitter rotor is turned. When power is again applied to the system, the transmitter and receiver rotor shafts are in corresponding positions, but an indicator coupled to the receiver rotor shaft may not show the actual position of the device geared to the transmitter. The number of positions in which the transmitter and receiver rotor shafts can correspond is the same as the transmission speed. Thus, in 36-speed data transmission, we have 1 correct position and 35 incorrect positions.

4.14.4.2 Dual-speed system. For accurate transmission without loss of self-synchronous operation, a dual-speed system is used. The 1-speed dial is graduated through 360 degrees, and the 36-speed dial is graduated through 10 degrees. If both dials are read, a more accurate bearing indication is obtained. A common variation of the above employs two control transformers in place of the torque receivers. When the error (difference in position of transmitter and control transformer rotors), exceeds a certain value, the 1-speed synchro takes control and reduces the error to a small value. The 36-speed synchro then takes control and increases the accuracy.

4.15 Synchro capacitors.

4.15.1 The AC current drawn by a coil. It is stated in 1.4.3.3.1 that, in AC circuits, the current through a coil does not reverse at the same time as the applied voltage. The current reversal occurs after, or lags, the voltage by an amount of time determined by the coil impedance. Consider first what happens when an AC voltage is applied to a coil of wire wound on an iron core. The AC current that flows in this coil has a certain magnitude which depends on how the coil is made (in this example, it is 1 amp). If the instantaneous values of this current were measured with an oscilloscope and compared with the line voltage, the graphs would be as illustrated on Figure 42. Because such a coil is highly inductive, its current reaches each point in the cycle almost 1/4 cycle later than the applied voltage. In other words, the current lags the applied voltage by almost 90°

4.15.1.1 Differential or control transformer connected to a transmitter. When a differential or control transformer is connected to a transmitter, the transmitter must supply the stator currents to the other synchro. The total current supplied is the sum of two lesser currents: (1) the loss current, in phase with the applied voltage, which supplies the heat loss in the windings and laminations; and (2) the magnetizing current, lagging the applied voltage by 90 degrees, which produces the magnetic field. Figure 43 shows the relationship of these currents and the equivalent circuit of the coil.

4.15.1.2 Power. Because the currents are not in phase, the effective value of the actual current is less than the sum of the two values. By the same token, the effective power of a circuit in which the voltage and current are out of phase is less than the volt-ampere product. On Figure 44, the wattmeter indicates that the power supplied to the coil is one watt, while the volt-ampere product is two volt-amperes. As illustrated, the power factor is normally expressed as a percentage; it cannot exceed 100 percent.

4.15.2 The effect of a capacitor on coil current. The current drawn by a coil can be reduced by connecting a capacitor across it. In a capacitor, the current leads the applied voltage. On Figure 45, the capacitor used draws a current equal to the magnetizing current of the coil. The two out-of-phase currents cancel, and the actual current is only the loss current.

4.15.3 The use of capacitors with a control transformer. The simplest case in which capacitors are used is across the stator leads of a control transformer. Each of the three stator windings of a control transformer can be thought of as consisting of a high resistance (which draws the loss current) in parallel with an inductance (which draws the magnetizing current) as shown on Figure 46. When a control transformer is connected to a transmitter, the current in each stator lead depends on the position of the transmitter rotor and on the construction of the control transformer.

For example, the current in the S2 lead reaches its highest value when the transmitter is on 0 degrees (or 180 degrees). The current in the S2 lead of a typical control transformer measures about .032 amp (32 milliamps) as shown on Figure 47. This current consists of about 10 milliamps loss current, and about 30 milliamps magnetizing current. On Figure 48, the magnetizing current of each coil in the control transformer could be cancelled by connecting across it a capacitor which drew an equal and opposite current. Since there is no connection to the common lead available outside the synchro case, this installation would not operate very well.

4.15.3.4 Definition of a synchro capacitor. A synchro capacitor consists of three equal delta-connected capacitors (see Figure 49), which are mounted in a case. Synchro capacitors are made in various sizes to conveniently accommodate all standard differentials and control transformers. The synchro capacitor unit is rated according to the "total capacitance" which is the sum of the three capacitances.

4.15.3.5 Effect of synchro capacitor on a control transformer. When the synchro capacitor is connected to the stator leads of a control transformer, the magnetizing current of that unit is practically cancelled by the capacitor current, regardless of the transmitter shaft position. For example, the current drawn by the control transformer is reduced from 0.032 amp to 0.010 amp when the synchro capacitor is installed as shown on Figure 50.

4.15.4 The use of capacitors with a synchro differential. When a synchro differential is connected between a transmitter and a receiver, the stator currents are no longer zero when the shafts are lined up, as was explained in the paragraphs on differentials. Also, because current is being drawn from the transmitter and receiver stators, their rotor currents are higher than normal. In a typical case, the currents have the values shown on Figure 51.

4.15.4.1 Effect on currents by addition of a capacitor. Since the current drawn by the differential is largely magnetizing current, it can be greatly reduced by connecting the proper synchro capacitor across the differential's stator leads. This decreases the current drawn from the transmitter, increasing the transmitter's output voltage, thus giving a better balance and decreasing the current from the receiver. In the case shown above, the addition of a capacitor changes the currents as shown on Figure 52.

4.15.4.2 Rotor leads connected to a control transformer. A situation in which the use of synchro capacitors is even more essential than that described above, is where a transmitter feeds a differential whose rotor leads are connected only to a control transformer. In this case, the transmitter must supply all of the losses and magnetizing current for both the other units, so the current drawn from the transmitter stator leads is very high. The values measured in a typical case are shown on Figure 53.

4.15.4.3 Reduction of load by addition of capacitors. The load on the transmitter is greatly reduced by connecting the correct size synchro capacitor across the differential's stator leads and another across the control transformer's stator as shown on Figure 54.

4.15.5 General notes concerning synchro capacitors. Synchro capacitors are specifically designed to perform a particular function. It is recommended that substitutes, such as electrolytic and paper filter capacitors, should not be used. Use of these types will cause an inaccuracy in the system. The recommended type of synchro capacitor is of paper foil construction.

4.15.6 Synchro capacitor location in synchro system. A synchro capacitor should be mounted close to the differential unit or the control transformer. The intent of the synchro capacitor is rendered useless if the high magnetizing current of the unit is required to flow through an extensive length of wire before being cancelled by this capacitor (see Figure 55).

4.15.7 Use of capacitors to reduce line current of a transmitter or receiver. When a transmitter or receiver is connected to an AC supply, the current drawn by the rotor is largely magnetizing current (see Figure 56).

4.15.7.1 Effect of addition of capacitors. When capacitors are connected across the rotor leads of each unit, the current drawn from the AC supply can be greatly reduced as shown on Figure 57. Capacitors are not to be connected in the stator circuit between the transmitter and receiver. The current in this circuit is zero; therefore, the capacitor in this location will increase the current which will cause an inaccuracy in the system.

4.15.8 Synchro capacitor boxes. Due to the necessity of having the synchro capacitor mounted as close as possible to the synchro unit which requires a current correction, it is sometimes mandatory that the capacitors must be mounted in an exposed location. Therefore, synchro capacitors are mounted in boxes especially designed for this purpose. Tables II and III list synchro capacitor boxes available for this purpose.

4.15.9 Characteristics of Navy standard synchro capacitors. Table IV provides a list of Navy standard synchro capacitors and their replacements. Figure 58 illustrates the standard connections and current values of the capacitors listed in Table IV.

4.16 Special synchros (servtorqs). Servtorqs (special torque receiver-type synchros, synchro relay transmitters, and synchro amplifiers) have been developed and are available to boost the torque, change the speed ratio, change from 60 Hz to 400 Hz, or vice versa, for synchro systems. A servtorq is a self-contained, remote angular positioning and tracking device for converting input synchro data into an accurate shaft position.

It performs the functions of conventional instrument servomechanisms and synchro torque receivers. It consists of a DC motor, amplifier, power supply, and synchro control transformer (either 60 Hz or 400 Hz), all mounted in the same synchro frame. Details of these devices are available in MIL-S-81746 or upon request to Commanding Officer, Naval Air Engineering Center, Engineering Specifications and Standards Department, Code 53, Lakehurst, NJ 08733-5100.

5. LOAD LIMITS FOR MIL-S-20708 SYNCHROS

5.1 Load limits for MIL-S-20708 synchros in torque systems.

5.1.1 Torque system arrangements. The load of receivers that may be carried in a torque system depends upon the arrangement of the system. Three arrangements are discussed (as shown on Figure 59); Torque System C is a combination of the first two arrangements—Torque Systems A and B. Note on Figure 59 that the torque differential transmitter units in Torque Systems B and C are provided with power-factor-correcting capacitors to reduce the load current drawn from the other synchro units.

5.1.1.1 Torque System A. The primary factors controlling the limiting load of receivers are:

a. The allowed maximum receiver error under static operation.

b. The allowed temperature rise in the torque transmitter produced by circulating currents and by error currents.

In regard to receiver error, as the number of receivers in a system is increased, the receivers get weaker and they require larger position errors to overcome their restraining torque and follow the transmitter. Thus, an excessive system loading would produce excessive receiver errors. A practical solution is to limit the number of receivers to a value that gives a system torque gradient no less than two-thirds the value of the unit torque gradient of the receivers. As such, at full system load, the receivers will give 50 percent increase in the restraining torque component of position error as compared to that obtained by one receiver controlled by a duplicate size transmitter. The increase in the total position error is actually less than 50 percent because the electrical error component of position error is not dependent on the number of receivers in the system. The system torque gradient of equal size receivers in this system is given with sufficient accuracy by:

EQUATION NO. (1)

$$T_s \doteq \frac{2r}{n_a + r} T_{ur}$$

where

T_s = system torque gradient of each receiver

$$r = \frac{T_u}{T_{ur}} = \frac{\text{unit torque gradient of the TX or TDX used as a TX}}{\text{unit torque gradient of each TR}}$$

n_a = number of equal size TR's

For the limiting condition that $T_s = (2/3)\ T_{ur}$, the maximum number of equal size TR's reduces to the following:

$$(n_a)_{max} \doteq 2r \qquad \text{EQUATION NO. (2)}$$

The loads obtained by using equation (2) are listed in Tables V and XV for the different sizes of torque transmitters and receivers. In normal practice with the receivers used only for position indication, the error currents are small and the temperature rise of the transmitter and receivers will not be excessive.

5.1.1.2 Torque System B. The limiting number of differential units and receivers are based on the following:

a. The load current required to energize the differential units is limited to the value the torque transmitter can carry at a safe temperature rise and at a voltage regulation not exceeding 2 to 3 percent for 400-hertz units or 7 percent for 60-hertz units. The limiting regulation valve is higher for 60-hertz units than for 400-hertz TX's because 60-hertz TX's have poorer voltage regulation per unit current than 400-hertz units.

b. The minimum system torque gradient of the receivers is set at two-thirds the value of their unit torque gradient, as was done for Torque System A. In paragraph a above, it is assumed that the differential units in the system are energized solely by the TX unit, without contribution by the receivers. The allowable load determined in this manner will assure safe operation of the TX and TR units, regardless of how many receivers may be switched off the system. All 400-hertz TX units up to and including size 37 can supply unity power factor load current up to 3 percent regulation without excessive temperature rise and up to 7 percent regulation for 60-hertz units. The limiting number of TDX units in this system is given by:

EQUATION NO. (3)

$$(n_d)_{max} = \frac{I_{TX}}{I_{TDX}}$$

where

I_{TX} = unity power factor load current of the TX, or the TDX used as a TX, for 2 to 3 percent voltage regulation for 400 hertz and 5 to 7 percent for 60 hertz

I_{TDX} = corrected energizing current of a given size TDX

$(n_d)_{max}$ = limiting number of equal size TDX units

For equal size differential units and equal number and size of receivers on each differential, the system torque gradient of the receivers in this system may be specified by the following approximate formula:

$$T_s \cong \frac{2r_b}{n_b + r_b} T_{ur} \qquad \text{EQUATION NO. (4)}$$

where

$$r_b \cong \frac{n_d r_r}{n_d + r_d} \qquad \text{EQUATION NO. (5)}$$

and

T_s = system torque gradient of each TR

T_{ur} = unit torque gradient of the TR's

n_b = number of equal size TR's

n_d = number of equal size TDX units

$$r_r = \frac{T_u}{T_{ur}} \quad \frac{\text{unit torque gradient of TX, or TDX used as a TX}}{\text{unit torque gradient of TR}}$$

$$r_d = \frac{T_u}{T_{ud}} \quad \frac{\text{unit torque gradient of TX, or TDX used as a TX}}{\text{unit torque gradient of TR}}$$

For the limiting condition that $T_s = (2/3)T_{ur}$, the maximum number of receivers in this system, as calculated from equations (4) and (5), is given by the following formula:

$$(n_b)_{max} \cong 2r_b \qquad \text{EQUATION NO. (6)}$$

The loads that are calculated by using equation (6) are listed in Tables VI and XVI for different sizes of torque transmitters, differentials, and receivers.

5.1.1.3 Torque System C. In this system, there are two receiver loads, one on the primary side of the TDX units (load 1); the other on the secondary side (load 2). The number of differential units that may be used with each TX is the same as for Torque System B. As to the number of receivers that may be used in loads 1 and 2, these loads are dependent on one another, as well as on the size of the TX and on the size and number of the TDX units. In a system of this type, the loads are obtained from a consideration of the system torque gradient using a procedure similar to that given for Torque System B. A practical approach is to solve the torque circuit of the system under the following conditions:

a. Loads 1 and 2 each have equal size receivers.

b. All receivers are assumed to be at equal position error of less than 10 degrees.

c. The TDX units are of equal size and they carry equal shares of the receiver load 2.

d. The minimum system torque gradient of the receivers in load 2 is set at two-thirds the value of their unit torque gradient.

e. The load current required to energize the differential units is limited to the value that the transmitter can carry at a safe temperature rise and a voltage regulation not exceeding 2 to 3 percent for 400-hertz units or 7 percent for 60-hertz units.

The ratio of the system torque gradient of the receivers in loads 1 and 2 to their respective unit torque gradients may be expressed approximately as follows:

$$\frac{T_{s1}}{T_{u1}} \cong \frac{2\,\frac{Z_{q1}}{n_1}\left(\frac{Z_{qe}}{n_d} + \frac{Z_{q2}}{n_2}\right)}{\left(Z_q + \frac{Z_{q1}}{n_1}\right)\left(\frac{Z_{q1}}{n_1} + \frac{Z_{qe}}{n_d} + \frac{Z_{q2}}{n_2}\right) - \left(\frac{Z_{q1}}{n_1}\right)^2} \qquad \text{EQUATION NO. (7)}$$

and

$$\frac{T_{s2}}{T_{u2}} \cong \frac{2\,\frac{Z_{q2}}{n_2}\,\frac{Z_{q1}}{n1}}{\left(Z_q + \frac{Z_{q1}}{n_1}\right)\left(\frac{Z_{q1}}{n_1} + \frac{Z_{qe}}{n_d} + \frac{Z_{q2}}{n_2}\right) - \left(\frac{Z_{q1}}{n_1}\right)^2} \qquad \text{EQUATION NO. (8)}$$

where

T_{s1} = system torque gradient of each TR in load 1

T_{s2} = system torque gradient of each TR in load 2

T_{u1} = unit torque gradient of each TR in load 1

T_{u2} = unit torque gradient of each TR in load 2

Z_{q1} = quadrature axis impedance of each TR in load 1

Z_{q2} = quadrature axis impedance of each TR in load 2

Z_{qe} = quadrature axis impedance of each TDX

Z_q = quadrature axis impedance of transmitter

n_1 = number of equal size TR's in load 1

n_2 = number of equal size TR's in load 2

n_d = number of equal size TDX's

Comparison of equations (7) and (8) indicates that T_{s2}/T_{u2} is always less than T_{s1}/T_{u1} for equal size receivers; therefore, load 2 is subject to comparatively weaker torque. Equation (8), for T_{s2}/T_{u2}, must, therefore, be used to determine n_2 and n_1 and it is set equal to 2/3. The approximate expressions for n_2 and n_1 are shown below:

$$n_2 \doteq \frac{r_2 n_d \left(2 - \dfrac{n_1}{r_1}\right)}{r_d + n_d + n_1 \dfrac{r_d}{r_1}} \qquad \text{EQUATION NO. (9)}$$

$$n_1 \doteq \frac{r_1 (2 r_2 n_d - r_d n_d - n_2 n_d)}{r_2 n_d + r_d n_2} \qquad \text{EQUATION NO. (10)}$$

where

$$r_1 = \frac{T_u}{T_{ur1}} = \frac{\text{unit torque gradient of TX, or TDX used as a TX}}{\text{unit torque gradient of TR in load 1}}$$

$$r_2 = \frac{T_u}{T_{ur2}} = \frac{\text{unit torque gradient of TX, or TDX used as a TX}}{\text{unit torque gradient of TR in load 2}}$$

$$r_d = \frac{T_u}{T_{ud}} = \text{ratio of unit torque gradients of TX and TDX}$$

and n_1, n_2, and n_d are the same as above.

By setting n_1 equal to zero in equation (9), the following equation is obtained:

$$n_2 \doteq \frac{2r_2\, n_d}{r_d + n_d} \qquad \text{EQUATION NO. (11)}$$

Equations (6) and (11) are identical and yield the maximum number of receivers for Torque System B. Using this value as the starting point for Torque System C, the total number of TR's in load 2 is reduced by n_d, $2n_d$, $3n_d$, and so forth, until each TDX carries one TR and n_1 is calculated from equation (10) for each such reduction in load 2. The results obtained by this method are shown in Tables VII and XVII.

5.1.1.4 Discussion of Tables V, VI, VII, XV, XVI, and XVII. The following may be noted in connection with the tables:

a. All differentials energized from synchro transmitters are provided with power-factor-correcting capacitors. The values of these capacitors are tabulated in Tables VIII and XVIII. Without capacitors, the allowable number of differentials would be reduced to between one-third and one-fourth of the values shown in these tables.

b. Blocking bars are used to indicate that no satisfactory system can be formed within the indicated area.

5.2 Load limits for MIL-S-20708 synchros in mixed systems.

5.2.1 General. It has been common practice to employ mixed synchro systems in which control transformers and torque receivers are operated from a common transmitter. In such systems, the position error of the control load (CT units) has comparatively negligible effect on the accuracy of the torque load (TR units), especially when the CT outputs are fed into high load impedances. By contrast, even the normal position error of the torque receivers produces significant bus errors to impair the accuracy of the control load. In addition, this bus error is accompanied by some quadrature time phase voltage which may impair the sensitivity of the control servos on null positioning. For these reasons, the position accuracy of the control load in mixed synchro systems is not as good as in straight control systems.

5.2.2 Requirements for safe and accurate performance. To assure fairly accurate and safe performance of mixed systems, the following requirements should be met:

a. The transmitter must be the torque type (TX); not the control type (CX). Both types of transmitters can supply load currents to CT units, but only the torque transmitters have comparatively low impedance level for effective operation of torque receivers.

b. The differential transmitters intended to carry torque and control loads must be the torque type (TDX), whereas those intended to carry only CT units may be either torque differentials (TDX) or control differentials (CDX).

c. The load current to the CT and differential units should be limited to that producing not more than about 3 or 4 percent drop on the TX and CDX secondary voltages in 400-hertz units or 10 percent drop in 60-hertz units, assuming no contribution by the TR units in sharing the load current with the TX. This limiting regulation assures satisfactory accuracy in the system without excessive temperature rise in the TX, TR or differential transmitter, regardless of how many units may be switched off the system. In addition, with the above voltage drop limit, the reduction in output voltage gradient of the CT is limited to about 10 percent for 400-hertz units or about 15 to 20 percent for 60-hertz units.

d. Since mixed synchro systems have to employ torque type transmitters (TX's), the limiting loads can be determined by reference to Torque System Tables V, VI, VII, XV, XVI and XVII. In these torque systems, the limiting number of TR units is already indicated. It remains to determine the number of CT units that may be added to the torque systems, and the number of CDX-CT branches that may replace TDX-TR branches where the TR units are not needed. The following guides are suitable for determining limiting loads in mixed systems.

5.2.2.1 Mixed System A. The limiting number of CT's that may be added to the torque systems of Tables V and XV, which are TX-TR systems without intermediate TDX's, depends upon the size of the TX used and is shown in Tables IX and XIX.

5.2.2.2 Mixed System B. The limiting number of CT's that may be added to each section of the torque systems of Tables VI, VII, XVI and XVII, all of which contain intermediate TDX's, depends upon the number and size of the TR's in that section. Table X shows the limiting number of CT's that may be added to each TR of Tables VI and VII. Table XX shows the limiting number for Tables XVI and XVII. However, where the number of differentials of Tables VI and VII is given as a range without change of the TR load per differential, the limiting number of CT's in each differential branch may be increased if the system does not utilize the maximum number of TDX's. The number of CT units in each differential branch may be determined by the following formula:

$$n'_{ct} \doteq n_{ct} \left(3 - \frac{2n_d - 2}{n_{dm} - 1}\right) \qquad \text{EQUATION NO. (12)}$$

where

n'_{ct} = new value of CT load per TR in the differential branch

n_{ct} = CT load per TR of Table VII in the differential branch

n_d = actual number of TDX's carried in the system

n_{dm} = maximum number of TDX units allowed in the system

As an example, consider the following system from Table VI: 37TRX4A - (1 to 7), 18TDX4C - (1), 18TR4B or 18TRX4A per TDX. If 11CT4E units are used, reference to Table X shows that $n_{ct} = 3$. Assuming $n_d = 4$, solution of equation (12) yields $n'_{ct} = 6$.

5.2.2.3 Mixed System C. In this system, a branch consisting of a TDX with its load of TR's is removed from a torque system of Tables VI and VII and replaced by one or more CDX-CT branches. Tables XI and XXI show the limiting number of CDX's and the limiting number of CT's per CDX that may replace a TDX-TR branch.

5.2.2.4 Discussion of Tables IX, X, XI, XIX, XX, and XXI. Paragraphs 5.3.1.4 a, b, and c regarding use of power-factor-correcting capacitors for CDX and CT units, grouping of CT's and mixing of CT's, respectively, are equally applicable with regard to Tables IX, X, XI, XIX, XX, and XXI.

5.3 Load limits for MIL-S-20708 synchros in control systems.

5.3.1 Control system arrangements. The quantity of synchros that may be carried in a control system depends upon the specific arrangement of the system. The three arrangements shown on Figure 60 are discussed in the following paragraphs. The third arrangement is a combination of the first two. Note on Figure 60 that CT and CDX units are provided with power-factor-correcting capacitors. In this manner, the systems can carry about three to four times as many CDX and CT units connected directly to the CX, and CT units connected directly to the differential. The primary factors that limit synchro loading for the systems shown on Figure 60 are:

a. The limiting temperature rise of the CX and CDX units, produced by their respective load currents.

b. The allowed system regulation as a percent drop in voltage gradient of the control transformers, contributed by the CX, CDX and load impedance of the CT units.

c. The permissible load impedance on CT units, so as to limit the percent drop in voltage gradient and the reflection of position errors among CT units. In determining synchro loading limits, some allowance is made in the values of corrected energizing current of the CT and CDX units to account for normal variation in supply frequency and for variation in optimum capacity among units of the same type.

5.3.1.1 Control System A. The maximum number of CT's is determined by limiting system regulation, or the drop in voltage gradient of the CT, to approximately 10 percent in 400-hertz units or 15 to 20 percent in 60-hertz units. CX voltage regulation is limited to approximately 4 percent in 400-hertz units or 10 percent in 60-hertz units. The following equations are applicable:

$$VR_s = VR_{cx} + VR_{ct} \qquad \text{EQUATION NO. (13)}$$

$$I_{cx} = n_{ct}\, I_{ct} \cos\theta_{ct} \qquad \text{EQUATION NO. (14)}$$

where

VR_s = system regulation or drop in voltage gradient of a CT

VR_{cx} = voltage regulation of CX, or CDX used as a CX, due to unity power factor load current it delivers to all units

VR_{ct} = voltage regulation of a CT due to a minimum load impedance of 15,000 ohms across its secondary

I_{cx} = total corrected energizing current drawn from the CX or CDX used as a CX, by its load of CT's

n_{ct} = number of CT's in the system

I_{ct} = energizing current required by a CT

$\cos\theta_{ct}$ = power factor of a CT

Since VR_s is limited to approximately 10 percent for 400 Hz, 15 to 20 percent for 60 Hz, and VR_{ct} is measured, VR_{cx} may be calculated from equation (13). From experimentally determined data on voltage regulation, I_{cx} for the calculated value of VR_{cx} is obtained. Substituting this value of I_{cx} and the corrected energizing current of a CT, namely, $I_{ct} \cos\theta_{ct}$, into equation (14), the limiting number of CT's may be calculated. The results for Control System A are shown in Tables XII and XXII. For the specified loads, all units operate within their allowable temperature rise values.

5.3.1.2 Control System B. The maximum number of CT's and CDX's is determined by limiting system regulation, or the drop in voltage gradient of the CT, to approximately 10 to 20 percent. Also, voltage regulation of the CX is limited to about 3 to 4 percent in 400-hertz or 10 percent in 60-hertz units, and similarly for the CDX. The following equations are applicable:

$$VR_s = VR_{cx} + VR_{cdx} + VR_{ct} \qquad \text{EQUATION (15)}$$

$$I_a = n_{ct/cdx}\, I_{ct} \cos\theta_{ct} \qquad \text{EQUATION (16)}$$

$$I_b = I_{cdx} \cos\theta_{cdx} \qquad \text{EQUATION (17)}$$

$$I_{cx} \equiv n_{cdx}[I_a + I_b] \qquad \text{EQUATION (18)}$$

where

VR_s = system regulation or drop in voltage gradient of a CT

VR_{cx} = voltage regulation of CX, or CDX used as a CX, due to unity power factor load current it delivers to all units

VR_{cdx} = voltage regulation of a CDX due to unity power factor load current it delivers to its load of CT's

VR_{ct} = voltage regulation of a CT due to a minimum load impedance of 15,000 ohms across its secondary

I_a = total corrected energizing current drawn from a CDX by its load of CT's

$n_{ct/cdx}$ = number of CT's carried by a CDX

I_{ct} = energizing current required by a CT

$\cos\theta_{ct}$ = power factor of a CT

I_b = corrected energizing current drawn by a CDX

I_{cdx} = energizing current required by a CDX

$\cos\theta_{cdx}$ = power factor of a CDX

I_{cx} = total load current delivered by the CX, or CDX used as a CX, to power-factor-corrected CDX's and CT's

n_{cdx} = quantity of CDX's used in the system

To simplify calculations, n_{cdx} is selected as 1 for each new CX-CDX combination. The number of CT's carried by the differential is arbitrarily selected. For this condition, equations (16), (17), and (18) are solved. From experimentally determined data on voltage regulation, VR_{cx} and VR_{cdx} corresponding to I_{cx} and I_a, respectively, are calculated. As VR_{ct} is a measured value, all terms on the right side of equation (15) are known. The values of regulation for the terms in equation (15) are compared with the limiting values specified. The number of CT's carried by the differential is then decreased or increased as required, and the above procedure repeated until a limiting loading factor is reached. The process described above is repeated as n_{cdx} is increased progressively by one, until the limiting number of differentials is reached. The results for Control System B are shown in Tables XIII and XXIII. For the specified loads, all units operate within the allowable temperature rise values.

5.3.1.3 Control System C. There are two CT loads in this system; CT load 1 connected directly to the CX, and CT load 2 connected directly to the CDX. System regulation, or drop in voltage gradient of the CT, is always poorer for load 2 because voltage regulation of the CX affects both CT loads equally, but voltage regulation of the CDX is included in the system regulation for the CT's in load 2 only. For this reason, Table XIV, which lists the loads for this system, gives the limiting drop in voltage gradient for CT's in load 2 only. The same approach and equations hold for this system as for Control System B, except that VR_{cx} and I_{cx} include the loading due to the CT's energized directly by the CX (n_{ct} for load 1). Using the load limits of System B as the starting point, the CT's in load 2 are reduced by 1, 3 . . . units per CDX, until each CDX carries one CT. For each such reduction in load 2, the corresponding allowable increase in n_{ct} for load 1 is calculated.

5.3.1.4 Discussion of Tables XII, XIII and XIV. The following notes apply in connection with Tables XII, XIII and XIV.

a. All differentials energized from synchro transmitters and all control transformers are to be used with power-factor-correcting capacitors. The values for these capacitors are tabulated in Table VIII. Without power-factor-correcting capacitors, the differential and CT loads would be reduced to between one-third and one-fourth of the values shown in Tables XII, XIII and XIV.

b. 11CT4E and 15CT4C units are considered as a group in Tables XII through XIV because they have approximately equal weight on the system. Similarly, 18CT4C and 23CT4C units are considered as another group. The indicated quantity of CT's allowed for one group in Tables XII through XIV can be made up of either one type of CT or of both types of CT's in that group.

c. All systems carry more units of the 18CT4C and 23CT4C group than of the 11CT4E and 15CT4C group. These two groups of CT's may be mixed by proportional weight. For example, the system 23CX4D CT of Table IX may be used with the following subdivisions of load:

Quantity of CT's at Full Load

Transmitter	11CT4E or 15CT4C	plus	18CT4C or 23CT4C
23CX4D	0		70
23CX4D	5		60
23CX4D	10		50
23CX4D	15		40
23CX4D	20		30
23CX4D	25		20
23CX4D	30		10
23CX4D	35		0

d. The indicated load on each transmitter may be increased by approximately 100 percent when the control transmitter is replaced by a torque transmitter of the same size. For Control System C, Table XIV, this implies a 100 percent increase in load 1 and in the indicated number of CDX units, without altering the indicated load 2 per CDX unit. This larger load with the TX will not deteriorate the voltage gradient. However, the null voltage output of the CT units will likely be larger with the torque transmitter.

e. Blocking bars are used in Tables XII through XIV to indicate that no satisfactory system can be formed within the indicated area.

5.3.1.5 Discussion of Tables XXII, XXIII and XXIV. The following notes apply in connection with Tables XXII, XXIII and XXIV.

a. All differentials energized from synchro transmitters and all control transformers are to be used with power-factor-correcting capacitors. The values for these capacitors are tabulated in Table XVIII. Without power-factor-correcting capacitors, the differential and CT loads would be reduced to about one-third of the values shown in Tables XXII, XXIII and XXIV.

b. The 15CT6D and 23CT6D units are considered as a group in Tables XXII through XXIV because they have approximately equal weight on the system. The indicated quantity of CT's allowed in Tables XXII through XXIV can be made up of either one type of CT or of both types of CT's.

c. Of the three types of control transmitters and control differential transmitters that were available (18CDX6D, 23CX6D and 23CDX6C), only two satisfactory control systems can be set up. Consequently, available torque transmitters and torque differential transmitters were added in the determination of control systems. The CT null voltages of these systems may be several times higher than the CT null voltages for systems made up of control units only, because 60-hertz torque synchros generally have higher null voltages than control synchros.

d. Blocking bars are used to indicate that no satisfactory systems can be formed within the indicated area.

6. SYNCHROS IN ACTION

6.1 Synchro systems. Synchros are seldom used singly. They work in teams, and when two or more synchros are interconnected to work together, they form a synchro system. Such a system may, depending on the types and arrangement of its components, be put to uses which vary from positioning a sensitive indicator to controlling the motors which move a gun turret weighing many tons. If the synchro system provides a mechanical output which does the actual positioning, as in the case of the indicator, it is a torque system. If it provides an electrical output which is used only to control the power which does the mechanical work, it is a control system. Control synchros are usually part of a larger system called a servo, or automatic control, system. In many cases, the same system is called upon to perform both torque and control functions.

6.2 Torque synchro systems. The individual synchros which make up a torque system are designed to meet the demands placed on them by the mechanical load which such a system is expected to handle.

6.2.1 Transmitter and receiver. The simplest synchro system consists of one torque transmitter and one torque receiver connected in parallel as shown on Figure 61. It should be emphasized that the chief difference between the transmitter and the receiver is one of function. The transmitter is the unit whose shaft is turned; the receiver is the unit whose shaft follows. The two are not always interchangeable. They are electrically identical, but the receiver usually has an inertia damper and certain other refinements not present in the transmitter. In the following examples, forces equal and opposite to those turning the receiver rotor are present in the transmitter but do not affect its rotor position because the rotor is not free to turn. In practice, the transmitter rotor is mechanically connected, usually by gears, to the mechanism furnishing the information to be transmitted. The outstanding characteristic of the transmitter-receiver system is that, as soon as both rotors are connected in parallel to the same AC source, the receiver rotor assumes and holds the same electrical position as the transmitter rotor. Unless the transmitters and receivers are energized from the same AC source, the system cannot function properly. If the transmitter is positioned at 0 degrees, the receiver rotor turns to and remains at 0 degrees. If the transmitter is turned to 30 degrees, the receiver turns with it to 30 degrees.

6.2.1.1 Rotors in corresponding positions. Consider first the conditions existing in the transmitter-receiver system shown on Figure 62. Both transmitter and receiver rotors are at 0 degrees. In the transmitter, a maximum voltage of 52 volts is induced in the S2 coil by the alternating magnetic field of the rotor coil because the coupling between these two coils is maximum at 0 degrees. The S1 and S3 coils are so wound that at 0 degrees, the induced voltage across each coil is 26 volts, in phase with the S2 voltage, but less than maximum because S1 and S3 are less closely coupled to the rotor in this position. Since the receiver is electrically identical to the transmitter and the two rotors are connected in parallel, the voltage induced in each receiver stator coil exactly equals that of the corresponding transmitter stator coil. Notice, however, that in each case it also opposes the transmitter coil's voltage. The transmitter and receiver are like two AC generators producing equal voltages but working against each other. No current can flow in the transmitter through S1 and S2, or S3 and S2, because in the receiver equal and opposite voltages across S1 and S2, and across S3 and S2, oppose the current flow. In each complete electrical stator circuit of the system, the sum of the voltage is zero. No current flows in the stator coils to establish a magnetic field; therefore, no force is exerted on the rotors.

* NOTE *

> The fact that the rotors in this example are at electrical zero is not important. Similar static conditions result from any angular rotor position so long as it is the same for both rotors.

6.2.1.2 Rotors not in corresponding positions. Assume now that the transmitter rotor is suddenly turned to 30 degrees. The induced voltages across S2 and S3 immediately drop because coupling to the rotor has been decreased. Increased coupling increases the voltage across S1. The balance between transmitter and receiver stator voltages has been destroyed, and current flows in each stator circuit in direct proportion to the voltage unbalance existing in that circuit, as shown on Figure 63.

6.2.1.2.1 Affect on the receiver rotor. Examine the magnetic polarities established in the system at a particular instant, such as that assumed on Figure 64. It can be seen that in the receiver, each stator is acting as an electromagnet to turn the rotor in a counterclockwise direction. Since the rotor is free to move, it rotates to 30 degrees. At this point, it again induces stator voltages equal to those of the transmitter, current stops flowing in the stator coils, and their magnetic fields collapse.

6.2.1.2.2 Affect of different rotor positions. The same general idea works in any case where the two rotors are in different positions, regardless of what those individual positions may be. Figure 65 shows how the stator voltages and currents behave if the transmitter rotor is turned to 120 degrees while the receiver rotor is held at 60 degrees. In this example, coupling of the two rotors to corresponding stator coils differs more than in the previous case. The unbalanced voltages are, therefore, greater, and more stator current flows. As a result, the magnetic pull tending to turn the two shafts to identical positions is stronger than before. Figure 66 shows the magnetic polarities existing at a particular instant for this difference in rotor positions.

6.2.1.3 Reversing direction of receiver rotation. When the teeth of two mechanical gears are meshed, the gears turn in opposite directions. If a third gear is added, it turns in the same direction as the first. This is important here because synchro torque receivers are often connected through a train of mechanical gears to the device which they operate, and whether or not force is applied to the device in the same direction as that in which the receiver rotor turns depends on whether the number of gears in the train is odd or even. The important thing, of course, is to move the dial or other device in the right direction, and even when there are no gears involved, this may be opposite to the direction in which the receiver rotor of a normally connected system would turn. Either of these two factors, and sometimes a combination of both, may make it necessary to have the transmitter turn the receiver rotor in a direction opposite to that of its own rotor. This is accomplished by reversing the S1 and S3 connections of the transmitter-receiver system, so that S1 of the transmitter is connected to S3 of the receiver and vice-versa.

6.2.1.3.1 Rotors at various degrees. With the rotors at 0 degrees, conditions within the system remain the same as with normal stator connections, since the rotor coupling to S1 and S3 is equal. But suppose that the transmitter rotor is turned counterclockwise to 60 degrees as shown on Figure 67. In the transmitter, maximum rotor coupling induces maximum voltage across S1, which causes maximum current to flow through S3 in the receiver. The magnetic forces produced turn the receiver rotor clockwise into line with S3, the rotor's 300-degree position. At this point the rotor again induces voltages in its stator coils which equal those of the transmitter coils to which they are connected. Notice that only the direction of rotation changes, not the amount; 300 degrees is the same as minus 60 degrees.

* NOTE *

It should be emphasized here that the S1 and S3 connections are the only ones ever interchanged in a standard synchro system. Since S2 represents electrical zero, changing the S2 lead would introduce 120-degree errors in heading.

6.2.1.4 Stator currents. Whenever the rotors of two interconnected synchros are in different positions, current flows in the stator windings. The strength of the current flowing in each stator lead depends on the difference between the voltages induced in the two coils to which the lead connects. This voltage unbalance, in turn, depends on two things: (1) the actual positions of the rotors, and (2) the difference between the two positions.

6.2.1.4.1 Effect of difference between two positions. Suppose that an ammeter is inserted in any one of the stator leads (the S2 lead, for example), and that the two rotors are held so that there is a constant difference between their positions while they are rotated together until a point is found at which the ammeter indicates maximum stator current. If the difference between rotor positions is then increased and the rotation repeated, a different maximum reading is obtained. Each time the difference between rotor positions is changed, the maximum stator current that can be obtained by varying actual rotor positions is changed. Figure 68 is a graph showing how the value of the maximum stator current depends on the difference between rotor positions in a typical case.

*** NOTE ***

> In practical operation, the position of the receiver's shaft would never be more than a degree or so away from the transmitter's, so that maximum stator current under normal conditions would be less than one-tenth of an ampere for the synchros used in this example.

6.2.1.4.2 Actual rotor positions. To see how actual rotor positions, as well as the difference between them, affect individual stator currents, it is only necessary to compare the maximum stator current in each lead with the strength of the current in that lead as the two rotors are turned through 360 degrees. The difference in rotor position with which the maximum stator current was established should be maintained while turning the rotors. The graphs on Figure 69 show how the current in each of the three stator leads depends on the mean shaft position, the position that is halfway between the position of the transmitter rotor and that of the receiver.

6.2.1.5 Rotor currents. A synchro transmitter or receiver acts like a transformer, and an increase in the stator secondary current results in a corresponding increase in the rotor primary current. When the rotor current of either of the units is plotted on a graph under the same conditions as those used for maximum stator currents, it appears as shown on Figure 70. Although all three stator currents are zero when the shafts are in the same positions, the rotor current is not. As in any transformer, the primary draws some current with no load on the secondary. This current produces magnetization of the rotor and supplies its losses.

6.2.1.6 Why there is no torque at 180 degrees. Since the stator current increases with the difference in rotor position, and since the magnetic fields of the stators increase in strength with the stator current, it appears the torque or turning force exerted by the receiver's shaft should be greatest when the transmitter and receiver rotors are 180 degrees apart, but exactly the opposite is true. To understand this, first consider the current conditions in the synchro system shown on Figure 71. Since all the voltages aid each other, strong currents flow in all three stator leads. If the two units are the same size, the currents are the same as those which would flow if three stator leads were shorted together. Obviously, these strong currents produce powerful magnetic forces. To see why no torque results, consider the polarities existing in the system at the particular instant assumed on Figure 72. As powerful as they are, the forces exerted on the rotor work against each other in such a way that their effects are equal and opposite. The resulting torque is zero. In actual situations, the two shafts do not stay in these positions unless held there. The slightest displacement of either one destroys the balance, and they are rapidly brought into corresponding positions.

6.2.2 Torque synchro systems containing differential units. The demands on a synchro system are not always so simple as the positioning of an indicating device in response to the information received from a single source. For example, an error detector used in checking fire control equipment employs a synchro system to determine the error in a gun turret's position with respect to the training order supplied by a dummy director. To do this, the synchro system must accept two signals—one containing the training order and the other giving the turret's actual position. The system must then compare the two and position an indicator to show the difference between them, which is the error. Obviously, the simple synchro transmitter-receiver systems considered up to this point could not handle a job of this sort. A different type of synchro is needed; one which can accept the position-data signals simultaneously, add or subtract the data, and furnish an output proportional to the sum or difference which it finds. This is where the synchro differential comes into the picture, because a differential can perform all three of these functions.

6.2.2.1 Differential units. Synchro differential units are discussed briefly in 4.9. The stator of a differential is similar to that of the simple transmitters and receivers discussed in the preceding paragraphs, but the rotor is totally different. It is wound with three coils instead of one. It is assumed in the schematic diagrams of synchro differentials that the three rotor coils turn around an A axis in the center of the diagram, the electrical position of the rotor being shown by the arrow on the R2 lead. If AC current is flowing in either the stator or rotor coils, the voltages induced in the other group depend on the position of the rotor, since this determines how closely the coils are coupled to one another. If all circuits are complete, currents flow in both rotor and stator coils. These currents generate individual magnetic fields around each coil. The strength and direction of the magnetic field is determined by the strength and direction of the current flow in the coil.

6.2.2.2 Resultant magnetic fields in a transmitter and differential transmitter. Thorough analysis of the interaction of a synchro system's magnetic fields is extremely complex, but the overall effect is relatively simple. When current flows in the stator coils of any synchro, individual magnetic fields are produced around each coil. Lenz's law states that when current is flowing as the result of an induced voltage, the magnetic field which the current produces opposes the magnetic field which induced the voltage. In a synchro transmitter, the stator voltages are induced by the fluctuating magnetic field of the rotor. The individual magnetic fields around the stator coils therefore oppose the field of the rotor, and the stator coils are so wound and positioned that the individual fields combine to produce a resultant stator field which is opposite to the field of the rotor.

6.2.2.2.1 Direction of magnetic fields. The stator leads of a TX (torque transmitter) are connected to the corresponding stator leads of a TDX (torque differential transmitter) on Figure 73. The resultant stator field (shown by open arrow) produced in the TX directly opposes the TX rotor field (shown by solid arrow), since corresponding stator coils of the two units are in series. For example, if S2 of the TX is in series with S2 of the TDX, the current flow produces a resultant stator field of equal strength in the TDX. However, currents in corresponding stator coils of the TDX are opposite in direction. The direction of the stator field in the TDX is, therefore, opposite to the direction of the TX stator field, but identical to the direction of the TX rotor field. The TDX rotor coils are angularly spaced 120 degrees apart, in the same manner as the TX stator coils. The TDX stator field is identical to the TX rotor field, neglecting small circuit losses. The result is that the TDX stator field acts upon the TDX rotor just as the TX rotor field acts upon the TX stator. If the stators of a TR (torque receiver) are connected to corresponding rotor coils of the TDX, rotating the stator field of the TDX with respect to the rotor produces the same effect in the TR as turning the rotor of a TX in previous examples.

6.2.2.2.2 Position of stator field in relation to rotor is controlling factor. Before considering such an arrangement, however, it must be made clear that the controlling relationship in the TDX is the position of the TDX stator field with respect to the rotor, not with respect to the TDX stator. Suppose that the TX rotor in the previous example is turned to 75 degrees, and the TDX rotor is turned to 30 degrees as shown on Figure 74. The TDX stator field is now positioned at 75 degrees with respect to S2, but the angle at which it cuts the TDX rotor is 45 degrees, using the R2 axis as a reference. This is the angle which determines the signal which the TDX transmits. Notice that turning the TDX rotor 30 degrees counterclockwise decreased the angle between the TDX stator field and R2 by that amount.

6.2.2.3 How the differential transmitter subtracts. The manner in which the torque system containing a TDX subtracts one input from, or adds it to, the other can be figuratively described as the positioning of the magnetic fields. Figure 75 shows such a system connected for subtraction. A mechanical input of 75 degrees is applied to the TX and converted to an electrical signal which the TX transmits to the TDX stator. The TDX subtracts its own mechanical input from this signal, and transmits the result to the TR, which provides the torque system's mechanical output in the position of its rotor.

6.2.2.3.1 Rotors turned to 0 degrees. To understand how this result is accomplished, consider conditions in a TX-TDX-TR system when the TX and TDX rotors are turned to 0 degrees, as illustrated on Figure 76. It has been shown how torque is developed in a synchro receiver to bring its rotor into a position which corresponds to that of an associated transmitter. In the TX-TDX-TR system now being considered, the TDX stator field has taken the place of the TX rotor, as far as the TR is concerned, and the TDX rotor has taken the place of the TX stator. The TR rotor, therefore, follows the angular position of the TDX stator field with respect to R2 of the TDX. Since this is 0 degrees, the TR rotor turns to that position, and the system has solved the equation: 0 degrees - 0 degrees = 0 degrees.

6.2.2.3.2 Magnetic fields. On Figure 76, the directions of the TDX rotor field and the TR stator and rotor fields are also indicated. Theoretically, when the system is in perfect balance, the TDX rotor voltages equal and oppose the TR stator voltages, so that no current flows in these circuits. Actually, there is usually a slight unbalance in rotor positions due to friction in the TR, even under static conditions, and weak magnetic fields are generated. The purpose of the arrows is to indicate the directions which the various magnetic fields assume as they swing into position. Notice that a voltage unbalance between the TDX rotor and the TR stator produces a TDX rotor field which opposes the TDX static field, while the torque produced in the TR turns that rotor field so that it lines up with the TR stator field when the system comes into balance. This does not contradict Lenz's law, because the TR rotor is separately excited and its field is not the result of voltages induced by the TR stator field. Whenever two independent magnetic fields are in close proximity, they immediately align themselves if either is free to move.

6.2.2.3.3 With TDX rotor at 0 degrees and TX rotor at 75 degrees. The illustration on Figure 77 assumes that a 75-degree input is applied to the system by turning the TX rotor to the 75-degree position. The TDX stator field follows, and since the TDX rotor is at 0 degrees, it also induces a 75-degree signal which the TDX rotor transmits to the TR. The TR rotor accordingly turns to 75 degrees, and furnishes the system's mechanical output. This illustrates an important rule:

> **Whenever the TDX rotor is at 0 degrees, the input and output voltages of the TDX are equal, and nothing is subtracted from or added to the TX signal. The TR rotor follows the TX rotor exactly. In the present case, the system has solved the equation:**
>
> **75 degrees - 0 degrees = 75 degrees.**

6.2.2.3.4 With TDX rotor turned to 30 degrees. The actual subtracting function of the TDX becomes more apparent when its own rotor is turned to 30 degrees (see Figure 78). The TDX stator field remains at 75 degrees, controlled by the position of the TX rotor; but its angular position with respect to R2 is decreased by 30 degrees. The signal induced in the TDX rotor and transmitted to the TR is 45 degrees, the TDX having subtracted the amount which its own rotor is turned from the signal transmitted by the TX. **The equation solved now reads: 75 degrees - 30 degrees = 45 degrees.**

6.2.2.3.5 Clockwise rotation of TDX. The TX-TDX-TR system treats a clockwise rotation of the TDX rotor as a negative value. Suppose the TDX rotor is now turned from 0 degrees clockwise to 330 degrees with the TX rotor still at 75 degrees (see Figure 79). The rotation is, in effect, through an angle of minus 30 degrees, which is the amount that the TDX subtracts from the signal transmitted by the TX. The angle between the TDX stator field and R2 is increased to 105 degrees, and this is the signal transmitted to the TR, whose rotor turns to a corresponding position: **75 degrees + 30 degrees = 105 degrees.**

6.2.2.4 How the differential transmitter adds. Frequently, it is necessary to set up a TX-TDX-TR system for addition. This is done by reversing the S1 and S3 leads between the TX and TDX stators and the R1 and R3 leads between the TDX rotor and the TR. With these connections, the system behaves as illustrated on Figure 80. The 75- and 30-degree mechanical inputs applied respectively to the rotor of the TX and the rotor of the TDX are added and transmitted to the TR, whose rotor provides an output equal to their sum by turning to 105 degrees.

6.2.2.4.1 Effect of individual stator fields. The reason for this behavior lies in the effect of the individual stator fields on the resultant stator fields of both the TX and TDX. Consider what happens when the TX rotor is turned to 75 degrees while the TDX is set at 0 degrees (see Figure 81). In the TX, with the rotor at 75 degrees, increased coupling between the rotor and S1 increases the current in, and consequently the magnetic field around, that coil while the field strengths of S2 and S3 decrease proportionately. This causes the resultant field of the TX stators to rotate counterclockwise, remaining directly opposed to the rotor field. The system is now connected so that the increased current in S1 of the TX flows through S3 of the TDX, while decreased currents flow through S1 and S2. In the TDX, therefore, the strong field around S3 has a greater effect on the resultant stator field, which rotates 75 degrees clockwise.

6.2.2.4.2 Reversal of R1 and R3 leads. However, the R1 and R3 leads between the TDX and the TR are also reversed. Just as in the simple TX-TR system with S1 and S3 leads interchanged, torque is developed in the TR which turns the rotor in a direction opposite to the rotation of the TDX stator field. Thus, the TX-TDR-TR system connected for addition behaves in the same way as the system connected for subtraction as long as the TDX rotor is at 0 degrees. The TR rotor follows the TX rotor exactly.

6.2.2.4.3 Effect of TDX turned to 30 degrees. When the TDX rotor is turned to 30 degrees (Figure 82), the angle between the TDX stator field and R2 is increased by that amount. This appears to the TR as an additional rotation of the TDX stator field. In transmitting the TX signal to the TR, the TDX adds the amount its own rotor turns.

6.2.2.5 The differential receiver. As previously explained, the differential receiver mainly varies from the differential transmitter in its application. The TDX in each of the previous examples combined its own input with the signal from a synchro transmitter and transmitted the sum or difference to a synchro receiver, which provided the system's mechanical output. In the case of the differential receiver in a torque system, the differential unit itself provides the system's mechanical output, usually as the sum or difference of the electrical signals received from two synchro transmitters. Figure 83 illustrates this operation in a system consisting of two TX's and a TDR (torque differential receiver) interconnected for subtraction.

6.2.2.5.1 How the differential receiver subtracts. In considering the operation of the TDR, it is important to remember that its rotor currents do not flow as a direct result of the rotor voltages induced by the fluctuating stator field, but only as the result of an unbalance between these induced voltages and the induced stator voltages of the TX to which the TDR rotor is connected. When the rotor of this TX is turned, its stator voltages are changed, and current flows in both the TX stator and TDR rotor coils. The TDR rotor field established by these currents rotates in the same direction, with respect to R2, as the TX rotor. Unless the rotor of the TX connected to the TDR stator is turned by an equal amount, the TDR rotor and stator fields are displaced with respect to each other, and a strong magnetic torque immediately operates to bring the two fields back into alignment. Since the TDR rotor is free to move, it rotates accordingly, restores the voltage balance in the TDR rotor circuits, and reduces current flow to a low value. Figure 84 shows how this works in a system connected for subtraction when the TDR rotor is initially at 0 degrees, and the rotors of the two TX's are rotated from 0 degrees to 75 degrees and 30 degrees as shown. The signal from the TX connected to the TDR stator rotates the resultant stator field 75 degrees counterclockwise. In a similar manner, the signal from the other TX to the TDR rotor also rotates the resultant rotor field counterclockwise 30 degrees with respect to R2. However, since the two resultant fields are not rotated by equal amounts, torque is developed to bring them into alignment. The rotor therefore turns to 45 degrees, at which point the two fields are aligned. To bring its resultant field into alignment, the TDR rotor need only be turned through an angle equal to the difference between the signals supplied by the two TX's. This is the requirement of the system.

6.2.2.5.2 How the differential receiver adds. To set up the system just considered for addition of the inputs to the two TX's, it is only necessary to reverse the R1 and R3 leads between the TDR rotor and the TX to which it is connected. With these connections reversed, the system operates as shown on Figure 85. Figure 86 illustrates how resultant magnetic fields are positioned to produce this result, again assuming that the TDR rotor is initially at 0 degrees, while the two TX rotors are turned from 0 degrees to 75 degrees and 30 degrees as shown. The TDR stator field still rotates counterclockwise 75 degrees, but because of the reversed R1 and R3 connections of the TDR rotor, the rotor field rotates 30 degrees clockwise. The angular displacement of the two fields with respect to each other, then, is the sum of the signals transmitted by the two TX's. The magnetic force pulling the TDR rotor field into alignment with that of the stator turns the TDR rotor to 105 degrees.

6.2.3 Rules for connecting a differential unit. By interchanging various connections between a differential unit and the two synchros with which it is associated, it is possible to obtain several different relationships between the shaft positions of the three units. All the connections which may be used in a standard differential system are shown on Figure 87, with the corresponding relationship between shaft positions. The unit types are not specified in the illustration, since this varies with the application of the system. This does not affect the relationship of the shaft positions.

6.2.4 Factors that affect the accuracy of a torque synchro system. The accuracy of a synchro system is probably its most important characteristic. Torque system accuracy is determined by how closely the system's output shaft approaches the position indicated by the system's input or inputs. In such a system, perfect accuracy is never obtained. Regardless of how carefully receivers are constructed, electrical error and error due to friction and load, called receiver error, are always present. A small, but measurable, amount of torque is required to overcome this friction; and when a receiver rotor is in perfect alignment with the signal applied to its stators, no torque is produced. The receiver lags slightly before producing enough torque to overcome brush and bearing friction, and this lag is present as an error in any torque system.

6.2.4.1 Simple torque systems. In a torque system consisting of one transmitter and one receiver, two important factors must be considered to obtain maximum accuracy:

a. The friction on the shaft of the receiver must be reduced to an absolute minimum. To satisfy this requirement, the ball bearings used on synchro receivers are selected with extreme care and factory-lubricated according to strict military specifications. It is interesting to note that friction on the shaft of a transmitter does not affect the accuracy of the system itself, but only increases the power required to turn the equipment to which it is geared. This does not mean that transmitter friction is unimportant, because the drag which a synchro system places on associated equipment is always a factor to be considered; but the requirements concerning the mechanical tolerances and lubrication of a transmitter are less severe.

b. The torque gradient of the receiver must be relatively high with respect to its combined friction and load, so that a very small lag produces sufficient torque to overcome both. To satisfy the second requirement, both the transmitter and receiver must be large enough to meet the needs of the system. The impedance of synchro stator windings increases as the size of the units decreases. If either or both units used in a system are too small, the high impedance of the stator windings reduces the stator current flow produced by a small lag, and thus reduces the receiver's torque gradient.

6.2.4.2 Torque systems involving a number of receivers. In a torque system where either a TX or TDX drives several receivers, the accuracy with which each receiver follows the position-data signal applied to its stators is determined by the following factors:

a. The friction and load on the shaft of that receiver.

b. The friction and loads on the shafts of all the other receivers. If any one of the receivers is excessively loaded, or if it becomes jammed, the accuracy of the whole system is affected.

c. The unit torque gradient of the transmitter as related to the number and size of the receivers it is driving. If too many receivers are connected to a particular transmitter, its output voltages are reduced and an excessive overall lag is produced in the system. This was previously discussed in section 4.

6.3 Control synchro systems. The comparatively small mechanical output of a torque synchro system is suitable only for very light loads; and even when it is not heavily loaded, a torque system is never entirely accurate. The receiver rotor requires a slight amount of torque to overcome its static friction, and this torque can only be produced by a small error in the system. Torque systems place a drag on associated equipment, which affects their accuracy. When larger amounts of power and a higher degree of accuracy are required as in the training mechanism of a heavy radar antenna, torque synchro systems give way to control synchros used as components of servo systems. Synchros control and servos provide power.

6.3.1 The control transformer. The distinguishing unit of any synchro control system is the control transformer (CT) described in paragraph 3.1.1.7. Remember that the CT is a synchro designed to supply, from its rotor terminals, an AC voltage with magnitude and phase dependent on its rotor position and on the signal applied to the three stator windings. The behavior of the CT in a system differs from that of the synchro units previously considered in several important respects.

a. Since the rotor winding is never connected to the AC supply, it induces no voltages in the stator coils. As a result, the CT stator currents are determined only by the voltages applied to the high impedance windings. The rotor itself is wound so that rotor position has very little effect on the stator currents.

b. There is never any appreciable current flowing in the rotor because its output voltage is always applied to a high impedance load of 10,000 ohms or more. Therefore, the rotor does not turn to any particular position when voltages are applied to the stators. The rotor shaft of a CT is always turned by an external force, and produces varying output voltages from its rotor winding.

c. Like synchro transmitters, the CT requires no inertia damper; but unlike either transmitters or receivers, rotor coupling to S2 is minimum when the CT is at electrical zero (see Figure 88).

6.3.1.1 Relationship of the stator voltages in a CT to the resultant magnetic field. When current flows in the stator circuits of a CT, a resultant magnetic field is produced. This resultant field can be rotated by the signal from a synchro transmitter or synchro differential transmitter in the same manner as the resultant stator field of the TDX previously considered. When the resultant field of the CT stator is at right angles to the magnetic axis of the rotor, the voltage induced in the rotor is zero. When the resultant field and the rotor's magnetic axis are aligned, the induced rotor voltage is maximum. Since no opposing voltages are induced in the stator of the CT, the effective strength of the resultant field is constant, regardless of its position. The strengths of the individual fields which make it up, however, vary with the current in the individual stator coils and, therefore, with the individual stator voltages. This means that the phase and magnitude of the stator voltages determine the direction of the resultant magnetic field. Since the CT's output is expressed in volts, it is convenient to consider its operation in terms of stator voltages, as well as in terms of the position of the resultant magnetic field. However, it should be remembered that it is the angular position of this fluctuating magnetic field with respect to the rotor axis that determines the output of the CT.

6.3.1.2 Operation of the control transformer with a synchro transmitter. Consider the conditions existing in the system shown on Figure 88, where a CT is connected for operation with a CX (control transmitter) and the rotors of both units are positioned at 0 degrees. The relative phases of the individual stator voltages with respect to the R1 to R2 voltage of the transmitter are indicated by the small arrows. The resultant stator field of the CT is shown in the same manner as for the TDX. With both rotors in the same position, the CT stator field is at right angles to the magnetic axis of the rotor coil. Since no voltage is induced in a coil by an alternating magnetic field perpendicular to its axis, the output voltage appearing across the rotor terminals of the CT is zero.

6.3.1.2.1 Example of CT rotor turned to 90 degrees and CX rotor at 0 degrees. On Figure 89, the CT's rotor position does not affect stator voltages or currents. The resultant stator field of the CT remains aligned with S2. The axis of the rotor coil is now in alignment with the stator field. Maximum voltage, approximately 55 volts, is induced in the coil and appears across the rotor terminals as the output of the CT.

6.3.1.2.2 Example of CT at 90 degrees and CX rotor turned to 180 degrees. On Figure 90, the electrical positions of the CX and CT are 90 degrees apart, the CT stator field and rotor axes are aligned, and the CT's output is maximum again, but the direction of the rotor's winding is now reversed with respect to the direction of the stator field. The phase of the output voltage is, therefore, opposite to that of the CT in the preceding example. This means that the phase of the CT's output voltage indicates the direction in which the CT rotor is displaced with respect to the position-data signal applied to its stators.

6.3.1.2.3 Variation of CT output. It is evident that the CT's output can be varied by rotating either its rotor or the position-data signal applied to its stators. It can also be seen that the magnitude and phase of the output depend on the relationship between signal and rotor rather than on the actual position of either. The graphs on Figure 41 illustrate the difference in the CT output when the CT rotor is first rotated through 360 degrees with the CX rotor at 0 degrees, and with the CX rotor at 90 degrees.

6.3.1.2.4 Summary. The important points to remember about the operation of a CT are these:

a. When the CT's rotor is in the same electrical position as the position-data signal applied to its stator (that is, in the same position as the resultant stator field), the electrical output of the unit is at a null.

b. When displacement with respect to each other is less than 90 degrees, any change in the angular relationship between the rotor and the position-data signal produces a corresponding change in the magnitude of the CT's output.

c. The direction of CT rotor displacement with respect to the position-data signal is always indicated by the phase of the CT's output voltage.

6.3.1.2.5 Rotor displaced 180 degrees. As indicated on Figure 41, the electrical output of the CT is also zero when the rotor is displaced with respect to the position-data signal by 180 degrees. It is, therefore, necessary to identify the CT rotor position at which 0 volts indicates agreement with the signal. In the case of the simple CX-CT combination, this is done by the phases of the two rotor voltages. If the CX and CT rotors are in the same position, the CT rotor voltage is zero. Turning the rotor slightly counterclockwise from the "0 volt" position produces a voltage from R1 to R2 on the CT that is in phase with the voltage from R1 to R2 on the CX. In practical applications of the CT, its rotor is positioned for proper operation in a particular system by one of the zeroing procedures described in section 10. Consideration of the servo systems discussed in following paragraphs of this section also show that a 180-degree displacement of the CT rotor can usually be detected in the behavior of the system's output.

6.3.2 Errors in control synchro systems. Three factors which produce errors in control systems are (1) electrical error, (2) errors inherent in control transformers, and (3) errors resulting from the use of torque and control units in the same system.

6.3.2.1 Electrical error. As defined in 4.13.5, the difference between the actual physical position and the electrical position of a synchro is known as electrical error. Consider a control system consisting of a control transmitter and a control transformer. If the CX and CT each have an electrical error of 12 minutes, the total possible electrical error is 24 minutes or nearly half of one degree. Adding a control differential transmitter having an electrical error for rotor and stator of 10 minutes each to this system, the total error increases to a possible 44 minutes or about three-fourths of a degree. The effect of such an error depends on the use of the particular system. In a gun training system, a one-half or 1-degree error becomes more pronounced at increased distances. The fact that synchro transmitters, differential transmitters, and control transformers are driven does not make them free from electrical errors. Manufacturing irregularities in the windings and the magnetic structure are inherent in all synchros.

6.3.2.2 Errors of control transformers. In a simple CX-CT system, it usually is assumed that the null position for the CT rotor always occurs when the axes of the CX and CT rotors are at 90 degrees displacement; however, this is seldom true. As an example, if a CX and CT are so positioned that the CT output is minimum and then the CX rotor is turned exactly 15 degrees, the CT rotor usually must be turned slightly more or less than 15 degrees to again obtain a null reading.

*** NOTE ***

A null or minimum reading, rather than a zero reading, has been specified.

The voltage output of a CT never becomes zero, but generally, at correspondence, falls as low as 50-125 millivolts for 115-volt synchros. Also, the null voltage obtained varies as the CX rotor position is varied. It is usual practice for a servo system to operate in such a manner that the CT output is a null. It should be obvious, therefore, that any variation in the position at which a null is obtained is reflected as an error in the entire system. Corrective measures also must be taken to compensate for phase shift in a servo. The impedance of the synchro windings causes the CT voltage to lead the CX supply voltage.

6.3.2.2.1 Error from use of multiple CT's. In a system where more than one control transformer is used, if the drive to one of the control transformers is inoperative, that CT may introduce error into the system which increases as the angle between its correct and actual position increases.

6.3.2.2.2 Speed error of CT's. When control transformers are rotated at high speeds, an additional error may be introduced. This is known as speed error. The null voltage position of the control transformer no longer occurs when the CT rotates in synchronism with the transmitter, but occurs when the CT rotor is at an angle to its correct synchronous position. The angle depends upon the speed of rotation, and usually lags behind that obtained under static conditions. As the number of CT's in a system increases, the speed error is apt to increase. Also, the speed error for a given speed is comparatively larger for a smaller size transmitter. Considering CT's of the same size and rotating at the same speed, the speed error is normally less for 400-hertz units than for 60-hertz units. Corrective devices are used to compensate for speed error.

6.3.2.3 Errors when torque and control units are used in the same system. Many systems use both torque and control units; however, the use of torque units in a control system should be avoided where accuracy is of prime importance.

6.3.2.3.1 Receiver error. In addition to electrical error, TR's and TDR's are subject to receiver error, the difference between the position assumed by the TR or TDR and the position transmitted by the TX, which often is as great as one degree. Receiver error affects the electrical output of the transmitter so that the electrical signal heading on the synchro bus differs from the actual transmitter position. Receiver error, also called position error, is caused by brush and bearing friction and the actual receiver load. Any increase in friction or load on a TR or TDR, or adding more TR's or TDR's to the system, increases the resultant bus error. Smaller receivers, sizes 11, 15 and 16, have such a low torque gradient value that, as lubricant deteriorates with use and bearings become dirty, the receiver error increases. Receivers also are subject to oscillations, and irregular or excessive oscillations are reflected as an additional bus error. When torque and control units are used in the same system, excitation must be supplied by a torque transmitter rather than a control transmitter.

6.4 Servo systems using synchros. A servo, servo system, or servomechanism (the three terms mean the same thing) is an automatic control device widely used in the Navy and distinguished by several special characteristics described here. There are many different types of servo systems, not all of which use synchros. This handbook, however, is primarily concerned with those which do.

6.4.1 Servo systems using control synchros. The purpose of servo systems in which control synchros are used is to supply larger amounts of power and a greater degree of accuracy than is possible with synchros alone. Another equally important characteristic of the servo is its ability to apply this power automatically, at the proper time, and to the degree regulated by the need at each particular moment. All the system requires to perform the specific task for which it is designed is an order defining the desired result. When such an order is received, the servo compares the desired result with existing conditions, determines the requirement, and applies power accordingly, automatically correcting for any tendency toward error which occurs during the process. To function in this manner, a servo system must meet five basic requirements:

a. It must be able to accept an input order defining the desired result and translate this order into usable form.

b. It must feed back, from its output, data concerning the existing conditions over which it exercises control.

c. It must compare this data with the desired result expressed by the input order and generate an error signal proportional to any difference which this comparison shows.

d. It must, in response to such an error signal, issue the proper correcting order to change existing conditions to those required.

e. It must adequately carry out its own correcting order.

It follows from these requirements that any servo system is made up, at least in part, of certain fundamental components. In functional terms, the components normally found in a servo system using synchros are identified as a data input device, a data output device, an amplifier, a power control device, a drive motor, and a feedback device.

6.4.2 Classification of servos by use. A convenient classification of servo systems can be made in accordance with their uses, of which the two most common are position servos and velocity servos. The position servo is used to control the position of its load and is designed so that its output moves the load to the position indicated by the input. The velocity servo is used to move its load at a speed determined by the input to the system.

6.4.2.1 Servo systems which do not fit into either category. For example, a third type of servo is used to control the acceleration rather than the velocity of its load. Special applications of the different types are used for calculating purposes, the servo making a desired computation from mechanical or electrical information and delivering the answer in the form of mechanical motion, an electrical signal, or both.

6.4.2.2 Position servo. A position servo is one in which the input order indicates a position in which the load is to be placed. Figure 91 shows the basic operation of a typical position servo which has wide application in Navy equipment. The load, in this case, is a gun turret. The overall purpose of the system is to train the gun by means of a remote hand crank. The load is mechanically coupled through a gear train to the rotor of a CT in such a manner that the turret's position is always accurately represented by the position of the rotor. An order signal expressing the desired position of the load is fed into the servo by positioning the rotor of the CX. A corresponding position-data signal immediately appears across the CT stator. When this signal differs from the actual position of the load, an AC error voltage is developed across the CT rotor. The phase of the error voltage is dependent on the angular direction in which the load must be moved to agree with the order signal.

6.4.2.2.1 Positioning the load. The amplifier retains this phase distinction, and feeds the amplified signal to the power control device where it is converted into power with a polarity or phase relationship which drives the motor in the direction necessary to bring the load into the desired position. As the load moves, mechanical feedback coupling turns the CT rotor toward agreement with the position-data signal. As the load approaches the proper position, therefore, less and less power is supplied to the motor because of the decreasing error voltage developed in the CT. The error voltage reaches zero and power is cut off from the motor when the electrical position of the CT rotor agrees with the position-data signal across the stator.

6.4.2.2.2 Oscillation. In an actual system, the momentum of the load tends to carry it past the desired position, and a new error voltage is developed to drive it back. If unchecked, this action results in hunting, which is oscillation of the load around the desired position. In most servos, an electronic network known as an anti-hunt system is used to minimize this undesirable effect.

6.4.3 Servo system ratings. Servo systems are qualitatively rated in accordance with the following characteristics:

a. Static error. The angular lag between the input and output under static conditions. A low figure is desirable.

b. Static error under load. The angular lag produced between input and output by applying a specific torque to the output. A low figure is desirable.

c. Velocity figure of merit. This figure is obtained by dividing the velocity of the output, expressed in degrees per second, by the angular lag between output and input, expressed in degrees, when the system is moving its load at a constant speed. It indicates how quickly the system responds to a constant input. A high figure is desirable.

d. Damping constant. This is related to the transient response of a servo. An overdamped servomotor is sluggish and usually responds to a change without overshooting. A slightly underdamped servomotor usually gives a quick response to a change with only moderate overshoot and practically no oscillation. A greatly underdamped servomotor will usually overshoot badly and oscillate for some time after a change in position is called for. The slightly underdamped case is the most desirable.

e. Acceleration figure of merit. The ratio between a constant acceleration of the system, expressed in degrees per second, and the angular lag between output and input, expressed in degrees. A high figure indicates system ability to follow an increasing or decreasing input accurately and rapidly.

7. MILITARY SYNCHRO TYPES

7.1 Designation codes. It is common practice to refer to synchros by their official designation; namely, 15CX6C, 18TRX4A, 26V-11TX4C, 5DG, and so on. The numerals and letters of a designation identify a synchro by correlation with its size and function. Two existing designation codes will be described herein for convenience. These are the "Military Standard Type Synchro" and the "Pre-Standard Type Synchro".

7.1.1 Military standard type synchro designation code. This code, currently in use, has been designed to fully identify a synchro unit by inspection of its nomenclature. Consider the three units (15CX6C, 18TRX4A, 26V-11TX4C) mentioned above. The first two digits of each unit's designation indicate the diameter in inches and tenths of inches, according to the following list:

0.01 to 0.10 = .1

0.11 to 0.20 = .2

0.21 to 0.30 = .3

0.31 to 0.40 = .4

0.41 to 0.50 = .5

0.51 to 0.60 = .6

0.61 to 0.70 = .7

0.71 to 0.80 = .8

0.81 to 0.90 = .9

0.91 to 1.00 = 1

Thus, a synchro whose actual diameter is 1.437 inches would be designated size 15.

7.1.1.1 Function of the synchro. The letters of the designation relate to the function of the unit. The first letter is either a "C" for a Control type, or "T" for a Torque type. The second letter identifies the following specific functions:

D - differential
R - receiver
T - transformer
X - transmitter

A third letter may be used; for example, "B" for a rotatable stator or bearing-mounted stator. Such devices are not too common and are no longer considered standard for new design.

7.1.1.2 Supply frequency. The numeral immediately following the letters designates the operating frequency of the device. The two common power supplies used by the military are:

6 - 60-hertz AC supply
4 - 400-hertz AC supply

7.1.1.3 Modification. The upper case letter following the operating frequency is the modification designation. Therefore, the letter "A" indicates the original or basic issue of a standard synchro type. The first modification is indicated by the letter "B", and succeeding modifications shall be "C", "D", and so on, except "I", "L", "O" and "Q" shall not be used.

7.1.1.4 Summary. To review, a synchro classified as 15CX6C indicates the second modification to the original design of a 115-volt, 60-hertz synchro control transmitter whose body diameter is greater than 1.40 inches, but not greater than 1.50 inches. Type designation 18TRX4A indicates the original design of a 115-volt, 400-hertz synchro torque receiver-transmitter having a body diameter greater than 1.70 inches, but not greater than 1.80 inches. A synchro having a type designation of 26V-11TX4C indicates the second modification to the original design of a 26-volt, 400-hertz synchro torque transmitter whose body diameter is greater than 1.00 inch, but not greater than 1.10 inches.

7.1.2 Pre-standard type synchro designation code. The pre-standard code identifies a synchro by size (Table XXV) and function (Table XXVI). The numeral indicates the size arbitrarily, whereas the standard code discussed previously is direct-reading.

7.2 Military specifications and standards for synchros.

7.2.1 Standard synchros. Standard synchros are designed, fabricated and tested according to the general specification, MIL-S-20708, approved by the Departments of the Army, Navy and Air Force. Requirements for the individual synchro types are stated in specification sheets to the general specification; for example, MIL-S-20708/1, "Synchro Control Transformer, Type 11CT4E."

7.2.1.1 Design of new equipment. To assure that the services are aware of the synchro types presently considered to meet the rigors of use, MIL-STD-710, "Synchros, 60 and 400 Hertz", has been prepared. This standard is revised periodically to inform designers of military equipment of those synchros currently recommended for service use. Synchros for new equipments are to be selected in accordance with the latest issue of MIL-STD-710. Table XXVII lists standard synchros which are currently qualified for use at the date of the revision of this handbook. The latest revision of each synchro's specification sheet should be used in new design. Figure 92 shows nine actual units, arranged to show a comparison in their size. Table XXVIII lists MIL-S-20708 synchros which are not presently on the Qualified Products List, but are capable of meeting the requirements.

7.2.1.2 Pre-standard synchros. Pre-standard synchros, shown on Figure 93 and listed in Table XXIX, have been designated as "obsolete for new design." Thus, they may be procured as replacements for failed synchros in equipment currently used by the services. However, when such equipments are being reordered, the design should be modified to use equivalent standard synchros wherever feasible.

8. HARDWARE, TOOLS, AND MOUNTING METHODS

8.1 General. To facilitate synchro mounting and attaching gears or dials to synchro shafts, several items of hardware have been developed. The different mounting methods and the manner in which items of hardware are used are described here. Special tools designed for use with the different hardware items also are available. The mounting methods described here are recommended, but special requirements may exist for specific installations.

8.2 Hardware for standard units.

8.2.1 Mounting clamp assembly. The clamp assembly illustrated on Figure 94 consists of a captive screw, lockwasher, and clamp. Three clamp assemblies, displaced from each other by 120 degrees, may be used to mount a synchro or they may be used in conjunction with the adapter assembly or zeroing ring as described in 8.2.3 and 8.2.4.

8.2.2 Clamping disc assembly. A clamping disc assembly consists of a clamping disc (see Figure 95), four captive screws, and four lockwashers. Assemblies are made for use on MIL-S-20708 size 11, 15, 16, 18, and 19 synchros. The four screws fit into threaded holes on the front (shaft end) of the synchro and, as illustrated under mounting methods, the pressure of the clamping disc against the panel or chassis holds the synchro in place.

8.2.3 Adapter assemblies. An adapter assembly, Figure 96, consists of an adapter plus four captive screws and lockwashers. These assemblies may be used on size 11, 15, 16, 18, and 19 synchros. The four screws fit into the four tapped holes on the front (shaft end) of the synchros. When an adapter assembly is used, the synchro is secured to the chassis or panel by using three mounting clamp assemblies.

8.2.4 Zeroing ring. Zeroing rings, Figure 97, are made to fit eight sizes of standard synchros. The zeroing ring is a flat spring steel ring having one sector with 6 to 20 gear teeth. Adjacent to the geared sector is a tongue which fits into a slot in the synchro frame and prevents the ring from turning around the synchro. When a zeroing ring is used, the synchro is secured to the panel or chassis by using three mounting clamp assemblies.

8.2.5 Shaft nuts. Gears or dials are usually mounted on the shaft of a standard synchro, and the shaft nut, with the drive washer described in 8.2.6, is used to hold them in place. The three sizes are illustrated on Figure 98. The smallest size is made for shafts with size #5-44 thread and the larger size for shafts with a 1/4 inch-28 thread.

8.2.6 Drive washers. When a dial or gear is mounted on a synchro shaft, it is essential that there is no backlash between the shaft and the dial or gear. Drive washers are splined to fit the shaft, and are shaped so that when the shaft nut is tightened, the teeth will dig into the shaft. Two tapered drive dogs engage holes or slots in the dial or gear being mounted. The maximum width of the drive dog exceeds the hole diameter or slot width so that when the shaft nut is tightened, the drive dogs are forced into the holes or slots. The combined action of the oversize drive dogs and the teeth digging into the shaft assures an anti-backlash mounting. For locking the shaft nut, tabs are provided which may be bent around the nut. The four sizes of drive washer available are shown on Figure 99. They are made for shaft extensions having 13, 15, 21, or 22 teeth. Drive washers are either black nickel-plated brass or aluminum alloy and, normally, are provided with the synchro.

8.3 Tools for standard synchros.

8.3.1 Angular adjustment tools. Where synchros are mounted by the use of an adapter assembly, clamping disc assembly, or zeroing ring, it is possible to adjust them physically for electrical zero by the use of either straight or 90-degree pinion wrenches, as shown on Figures 100 and 101. The panel on which the synchro is mounted must be provided with a hole located so that when the pinion wrench is inserted in the hole, the teeth on the wrench engage the teeth in the adapter assembly, clamping disc, or zeroing ring. When the clamping arrangement is loosened, it is possible to adjust the synchro accurately for electrical zero. Use of the pinion wrenches is illustrated under mounting methods.

8.3.2 Socket wrench assembly. Socket wrench assemblies, illustrated on Figure 102, are designed to hold the splined shaft by means of an internally splined socket, and to tighten the shaft nut with the outer or larger socket. Wrenches are available for 13-, 21-, and 22-tooth shafts, but not for the 15-tooth shaft.

8.4 Methods for mounting standard synchros.

8.4.1 From shaft end using #4-40 screws. Where no angular adjustment is required, certain sizes of synchros may be mounted as illustrated on Figure 103. Size 11, 15, 16, 18 and 19 synchros have four equally spaced tapped holes for #4-40 screws. When mounting, screws are inserted through the panel or chassis and into the synchro frame. The depth of the tapped portion on the frame is only about 0.125 inch, and it is necessary to avoid using screws which are too long.

8.4.2 From terminal board end, using a clamping disc assembly. Where no angular adjustment is required, certain sizes of synchros may be mounted by using the clamping disc assembly as illustrated on Figure 104. The synchro is inserted into the panel or chassis from the terminal board end. Clamping discs are placed over the panel hole so that the captive screws can be screwed into the four holes on the synchro frame. Tightening these screws fastens the synchro to the panel. While the four captive screws are loose, the synchro may be rotated through 360 degrees for proper positioning.

8.4.3 From shaft end, using an adapter assembly. When a synchro must be inserted into the chassis from the shaft end, it is possible to mount a synchro by using an adapter assembly and three mounting clamp assemblies (Figure 105). The adapter assembly is secured to the synchro frame, the leads are attached to the synchro, the synchro is inserted into the panel, and the adapter assembly is fastened in place by the three mounting clamp assemblies. While the mounting clamp assemblies are loose, a pinion wrench may be inserted in the hole provided in the chassis and the adapter assembly may be rotated for angular adjustment.

8.4.4 From terminal board end, using an adapter assembly. Figure 106 shows how a synchro is inserted into the chassis from the terminal board end secured by an adapter assembly and three mounting clamp assemblies.

8.4.5 From terminal board end, using three mounting clamp assemblies. Another method, which may be used when access is from terminal board end and no angular adjustment is required, is illustrated on Figure 107. The synchro is inserted into the hole provided in panel or chassis and secured by three clamp assemblies spaced 120 degrees apart.

8.4.6 From terminal board end, using a zeroing ring. This is the only method which may be used for all standard synchro sizes. The zeroing ring is first placed on the synchro so that the tongue fits the frame and the ring cannot be turned, as shown on Figure 108. The synchro is inserted into the panel or chassis from the terminal board end, and is secured to the panel or chassis by three mounting clamp assemblies spaced 120 degrees apart.

8.5 Methods for mounting pre-standard synchros. Pre-standard synchros were supplied in three types of housings to permit mounting in one of the following ways.

8.5.1 Flange. Figure 109 illustrates the flange-mounted synchro, which is the most common pre-standard type. The mounting hole is cut to accommodate the flange and the synchro is then clamped in place with screws and washers.

8.5.2 Nozzle. Figure 110 shows a type 5N synchro, one of the few nozzle-mounted types procured by the Navy. Figure 111 is an end view of this unit, showing the location of mounting holes.

8.5.3 Bearing. In a bearing-mounted type synchro, the stator can also be rotated. Figure 112 shows one possible mounting arrangement. It is possible to mount the supports and the synchros vertically or, by the use of worm gears, to mount the unit so that the two shaft centerlines are at right angles. The arrangement shown is similar to that used in size 16 and 19 units.

8.6 Mounting gears and dials on synchros.

8.6.1 Standard synchros. Figures 113 and 114 illustrate a gear mounted on a standard synchro. Figure 113 shows that the gear is first placed on the splined shaft, the drive washer is then placed on the shaft so that its two drive dogs engage the gear, and the shaft nut is put on behind the drive washer. Figure 114 shows a cutaway view of the socket wrench being used to tighten the shaft nut. The slotted pinion of the inner wrench holds the shaft in position while the outer socket wrench is used to tighten the shaft nut. After the shaft nut is tightened and the socket wrench is removed, the tabs on the drive washer are bent to lock the shaft nut so that it cannot work loose as the synchro rotates. Figure 115 shows the recommended method for mounting adjustable dials on synchros. Figure 116 shows the recommended positioning of the drive washer and shaft nuts to insure maximum loading.

8.6.2 Pre-standard synchros. The shafts of pre-standard synchros are made so that a dial or gear may be attached to a shaft without using setscrews or pins through the shaft. A special wrench is used to remove, install, or adjust dials or gears mounted in this way. Figure 117 shows how dials and gears are mounted. On a receiver, the nut is tightened down to hold the hub of the dial tightly between the slotted washer on top and the thrust washer on the bottom, which rests on a step in the shaft. To adjust the dial's position, when setting zero for example, the nut is loosened, the outer part of the wrench is held to keep the shaft from turning, and the dial is turned. On a transmitter or control transformer, where the gear must drive the shaft, a pin may be used to keep the gear and slotted washer turning together. Since the slotted washer cannot turn, the gear is locked to the shaft.

8.6.3 Mounting dials on a double receiver. A method of mounting dials on a double receiver is illustrated on Figure 118. The procedure is as follows:

a. Remove the retaining ring on the outer shaft and the nut and washer from the inner shaft.

b. Place the hub on the shaft as illustrated, fitting it into the keyed position of the shaft.

c. Replace the retaining ring on the outer shaft to hold the hub in place.

d. Mount the spider on the hub using the spider clamp and three #4-40 machine screws. Be sure that the screws are not more than 0.25 inch in length; otherwise they will protrude through the back of the hub.

e. Mount the dial hub on the inner shaft and secure to the shaft using the washer and hex nut.

f. Mount the outer dial on the spider using three #4-40 machine screws about 0.25 inch in length.

g. Mount the inner dial on the hub using the dial clamp and three #4-40 machine screws.

9. STANDARD CONNECTIONS FOR SYNCHROS

9.1 The need for standard connections. In systems in which a great many synchro units are used, it is necessary to have a closely defined set of standard connections if confusion is to be avoided. The following conventions are usually followed unless there is good reason for doing otherwise.

*** NOTE ***

All diagrams are shaft-end views. In practice, any letter may be used in place of those shown. "B" indicates any single-letter bus, "BB" any double-letter bus, and so on.

9.2 Example of an "increasing reading". An example of an increasing reading would be a transmitter connected to the needle on the speedometer of a car, as shown on Figure 119. It would send out an increasing reading when the car went faster, and a decreasing reading when it went slower.

9.3 Standard wire designations. The five wires of a synchro system are numbered in such a way that the shaft of a normal receiver will turn counter-clockwise when an increasing reading is sent over these wires, provided it is connected directly as shown on Figure 120. A direct connection is obtained by connecting R1 to the single-letter bus, R2 to the double-letter bus, S1 to the low-numbered bus, S2 to the middle, and S3 to the high-numbered bus.

9.4 Two-speed systems. In a synchro system where similar information is transmitted at several different speeds, the numbered wires are marked 1, 2 and 3 for the lowest speed, 4, 5 and 6 for the next higher speed, and so on (see Figure 121).

9.5 Standard voltages. When an increasing reading is sent over the five wires of a synchro system, the voltages between the five wires change as shown on Figure 122.

9.6 Standard transmitter connections. Connect a transmitter to the bus as shown on Figure 123 in each case if it is to transmit an increasing reading when its shaft is turned in the indicated direction.

9.7 Standard receiver connections. Connect a receiver to the bus as shown on Figure 124 in each case if its shaft is to turn in the indicated direction when it receives an increasing reading.

9.8 Standard connections for differential transmitters. For a differential transmitter, the stator leads are connected to the transmitter circuit and the rotor leads are connected to the receiver or control transformer, as shown on Figure 125. An increasing reading will be transmitted when a constant stator input voltage is applied and the shaft is turned in the direction indicated. If an increasing reading is applied to the stator and the shaft is held stationary, then an increasing reading will be transmitted.

9.9 Standard connections for differential receivers. Connect a differential receiver to the busses as shown on Figure 126 in each case if, with constant voltages on one side, the shaft is to turn as indicated when it receives an increasing reading from the other side.

9.10 Standard connections for control transformers.

9.10.1 Stator lead connections. Connect the stator leads of a control transformer to the bus as shown on Figure 127 in each case if the shaft is to turn as indicated when following an increasing reading.

9.10.2 Rotor lead connections. Connect the rotor leads of a control transformer to the signal input terminals of the servo amplifier as shown on Figure 128 in each case if the shaft is to turn as indicated when following an increasing reading.

9.11 Standard connections for synchro capacitors. Whenever a differential or control transformer is used, mount a synchro capacitor of the proper size as close to the synchro as possible. Figure 129 shows the capacitor connections.

9.12 Standard connections for servo amplifiers. When a servo system is following an increasing reading, the signal input voltage is in phase with the AC supply voltage, and the output voltage is either positive (for a DC output), in phase with the supply (for a straight AC amplifier), or lags the supply by 90° (when there is a 90° shift in the amplifier). In each case the voltage is measured at the single-letter terminal on the servo amplifier with respect to the corresponding double-letter terminal (see Figure 130).

9.13 Standard connections for servomotors.

*** NOTE ***

> On commutator type motors with a double-ended shaft, rotation is observed when looking at the shaft end opposite the commutator.

9.13.1 Shunt-field DC servomotor. When a shunt-field DC servomotor is used, connect the motor as shown on Figure 131 in each case if the shaft is to turn in the indicated direction when following an increasing reading.

9.13.2. Split-series-field servomotor. When a split-series-field servomotor is used, connect the motor as shown on Figure 132 in each case if the shaft is to turn in the indicated direction when following an increasing reading.

9.13.3 Two-field induction servomotor. When a two-field induction motor is used, one field being excited from the line and one through the servo amplifier, connect the motor as shown on Figure 133 in each case if the shaft is to turn in the indicated direction when following an increasing reading.

9.14 The standard connections that apply to a typical servomotor. There are two possible connections for each unit in a servo system which has a shaft. The one to use is determined by the direction in which that shaft turns when the system is following an increasing reading. The indicated standard connections in this section determine connections at each point, as shown on Figure 134.

10. ZEROING SYNCHROS

10.1 The need for electrical zero. If synchros are to work together properly in a system, it is essential that they be correctly connected and aligned in respect to each other, and to the other devices with which they are used. Consider a synchro transmitter and receiver used in an echo-ranging sonar equipment to provide an indication of sound projector position. Unless the projector, indicator, and synchros are correctly aligned in respect to each other, the operator cannot be sure the indicated projector position is correct. The same situation would exist in a gun director train-indicating system used to show the position of the director so the guns might be trained accordingly.

10.1.1 Mechanical reference points. Electrical zero is the reference point for alignment of all synchro units. The mechanical reference point for the units connected to the synchros depends upon the particular application of the synchro system. When a synchro system is used to repeat ship's course data, the reference point would be true north. For radar or sonar equipment, the reference point could be the ship's bow or zero degrees. In a range or azimuth data transmission system, a specific distance or angle could be the reference point. Whatever the type of system, the electrical and mechanical reference points must be aligned.

10.1.2 Alignment of electrical and mechanical points. There are two ways in which this alignment can be accomplished. The most difficult way is to have two people, one at the transmitter and one at the receiver or control transformer, adjust the synchros while talking over telephones or other communication device. The better way is to align all the synchros to electrical zero. Units may be zeroed individually and only one person is required to do the work. Another advantage of using electrical zero is that trouble in the system always shows up in the same way. For example, in a properly zeroed TX-TR system, a short circuit from S2 to S3 causes all receiver dials to stop at 60 or 240 degrees.

10.1.3 Summary. Zeroing a synchro means adjusting it mechanically so that it will work properly in a system in which all other synchros are zeroed. This mechanical adjustment is normally accomplished by physically turning the synchro rotor or stator. Section 8 describes standard mounting hardware and gives simple methods for physically adjusting synchros to electrical zero.

10.2 Electrical zero conditions. For any given rotor position, there is a definite set of stator voltages. One such rotor-position, stator-voltage condition can be established as an arbitrary reference point for all synchros which are electrically identical. Specific definitions for electrical zero are given below.

10.2.1 Transmitters and receivers. A synchro transmitter, CX or TX, is zeroed if electrical zero voltages exist when the device whose position the CX or TX transmits is set to mechanical reference position. A synchro receiver, or TR, is zeroed if, when electrical zero voltages exist, the device actuated by the receiver assumes its mechanical reference position. In a receiver or other unit having a rotatable stator, the zero position is the same, with the added provision that the unit to which the stator is geared is set to its reference position. In the electrical zero position, the axes of the rotor coil and the S2 coil are at zero displacement and the voltage measured between terminals S1 and S3 will be minimum. The voltages from S2 to S1 and from S2 to S3 are in phase with the excitation voltage from R1 to R2. The actual terminal voltages should be as follows:

115-volt synchros	26-volt synchros
R1 to R2 - 115 volts S2 to S1 - 78 volts S2 to S3 - 78 volts S1 to S3 - 0 volts	R1 to R6 - 26 volts S2 to S1 - 10.2 volts S2 to S3 - 10.2 volts S1 to S3 - 0 volts

10.2.2 Differentials. A differential is zeroed if the unit can be inserted into a system without introducing a change in the system. In the electrical zero position, the axes of coils R2 and S2 are at zero displacement. Terminal voltages are as follows:

115-volt synchros	26-volt synchros
R1 to R3 - 0 volts	R1 to R3 - 0 volts
S1 to S3 - 0 volts	S1 to S3 - 0 volts
R3 to R2 - 78 volts	R3 to R2 - 10.2 volts
S3 to S2 - 78 volts	S3 to S2 - 10.2 volts
R2 to R1 - 78 volts	R2 to R1 - 10.2 volts
S2 to S1 - 78 volts	S2 to S1 - 10.2 volts

10.2.3 Control transformers. A synchro control transformer is zeroed if its rotor voltage is minimum when electrical zero voltages are applied to its stator, and turning the CT's shaft slightly counterclockwise produces a voltage between R1 and R2 which is in phase with the voltage between R1 and R2 of the CX or TX supplying excitation to the CT stator. Electrical zero voltages, for the stator only, are the same as for transmitters and receivers.

10.3 Zeroing procedures. The procedure used for zeroing depends upon the facilities and tools available and how the synchros are connected in the system. The procedures described in the following paragraphs show how synchros may be zeroed by use of only a voltmeter, synchro testers, or other synchros in the system. When zeroing differentials and control transformers, it is helpful to have a source of 78 volts for 115-volt units or 10.2 volts for 26-volt units. Figure 135 is a schematic diagram of an autotransformer. This device is a single-winding variable-tapped inductance. Many synchro systems have provisions for stowing or locking units in their electrical zero position if the gyro compass fails. An autotransformer, or any other transformer used for this purpose, would be a good source of the required 78 volts. Regardless of the method used, there are two major steps in each zeroing procedure--first, the coarse or approximate setting; second, the fine setting. Many units are marked in such a manner that the coarse setting may be approximated physically. On standard units, an arrow is stamped on the frame and a line is marked on the shaft extension, as shown on Figure 136. Standard synchros mounted by a clamping disc assembly, adapter assembly, or zeroing ring may be rotated by use of a straight or 90-degree pinion wrench as described in section 8.

10.3.1 Zeroing a transmitter (CX or TX) using a voltmeter. The most accurate results can be obtained by using an electronic or precision voltmeter having 0- to 250-volt and 0- to 5-volt ranges. On the 0- to 5-volt range, the meter should be able to measure voltages as low as 0.1 volt. Proceed as follows:

a. Set the unit, whose position the CX or TX transmits, accurately in its zero or reference position.

b. Remove all other connections from the transmitter's stator leads, set the voltmeter to its 0- to 250-volt scale, and connect as shown on Figure 137(A).

c. Turn the rotor or stator until the meter reads about 37 volts, or 15 volts for 26-volt units. This is the approximate zero setting.

d. Connect meter as shown on Figure 137(B).

e. Adjust rotor or stator for null, minimum, reading.

10.3.2 Zeroing a torque transmitter using a receiver or synchro tester. This method is potentially less accurate than those previously described, because it is based on the assumption that the other synchro used is accurate, which may or may not be true. Synchro Tester, MK 2 All Mods (described in the next section) is not sufficiently accurate to be relied on without question, and is for use on 115-volt, 60-hertz synchros only. A receiver should also be checked to be sure it is at electrical zero when its dial reads zero or the reference value.

a. Connect the receiver or synchro tester to the transmitter as shown on Figure 138.

b. Set the unit, whose position the TX transmits, accurately in its zero or reference position. Turn the transmitter until the receiver or synchro tester dial reads 0 degrees; the transmitter is now at the approximate zero setting.

c. Momentarily short S1 to S3. If the receiver or synchro tester dial moves when S1 is shorted to S3, the transmitter is not zeroed; shift it slightly and try again. When the TX is accurately zeroed, clamp it and reconnect for normal use. If the receiver dial does not read zero or the reference value, it is necessary to zero the receiver.

10.3.3 Zeroing a torque receiver (TR) with a free rotor. To zero a torque receiver with a free rotor, proceed as follows:

a. Disconnect stator leads and note normal connections for use when reconnecting.

b. Set voltmeter on 0- to 250-volt scale and connect as shown on Figure 139(A).

c. Temporarily connect jumper between S1 and S3 as shown by dotted line on Figure 139(A). Rotor will turn to 0 or 180 degrees. If meter reads about 37 volts (15 volts for 26-volt synchros), rotor is at

0 degrees; proceed to step d. If meter reads about 190 volts (38 volts for 26-volt units), rotor is at 180 degrees. With jumper disconnected between S1 and S3, turn rotor to approximate zero setting. Reconnect jumper; now synchro should go to 0 degrees. If meter reads 37 volts (15 volts for 26-volt synchros), proceed to step d.

d. Connect meter as shown on Figure 139(B).

e. Adjust rotor or stator for minimum voltmeter reading.

10.3.4 Zeroing torque receiver with rotor not free to turn. When a torque receiver rotor is not free to turn, it is necessary to zero it in a manner similar to that used for transmitters. A check on receiver zeroing may be made as follows:

a. Set the transmitter to the electrical zero position and connect a temporary jumper from S1 to S3 as on Figure 138. If the receiver's shaft moves more than a fraction of a degree when the jumper is connected, the transmitter is not set on 0 degrees and should be rechecked.

b. If the receiver shaft does not turn, unclamp synchro and rotate it until the receiver dial reads zero. Connecting and disconnecting the jumper several times so that the dial moves slightly may help to set the dial more accurately.

c. Clamp the receiver in position when finished and remove the jumper.

10.3.5 Zeroing a synchro receiver by electrical lock. If lead connections may be easily removed, remove all stator connections and reconnect as shown on Figure 140. The shaft will turn definitely to 0 degrees. Set the dial at its zero or reference position while the receiver is connected this way. If a source of 78 volts (10.2 volts for 26-volt units) is not available, 115 volts (15 volts for 26-volt units) may be connected to R1 and R2.

*** CAUTION ***

Do not leave connected using 115 volts for more than 1 or 2 minutes. Operation on higher than the rated voltage causes the synchro to overheat and may cause permanent damage.

10.3.6 Zeroing a differential transmitter using a voltmeter. A differential voltmeter may be most accurately zeroed by using an AC voltmeter having 0- to 250-volt and 0- to 5-volt ranges. The procedure is as follows:

a. Set the unit, whose position the CDX or TDX transmits, accurately in its zero or reference position.

b. Remove all other connections from the differential leads, set the voltmeter on its 0- to 250-volt scale, and connect as shown on Figure 141(A).

c. Unclamp the differential and turn it until the meter reads minimum. The differential is now on approximate electrical zero. Reconnect as shown on Figure 141(B).

d. Set the voltmeter on the 0- to 5-volt scale, and turn the differential transmitter until a null reading is obtained. Clamp the differential in this position and reconnect all leads for normal operation.

10.3.7 Zeroing a torque differential transmitter using a receiver and torque transmitter. The transmitter and receiver used may be part of the system in which the differential is used or separate units such as the Synchro Tester, Mk 2 All Mods.

a. Check to see if the differential needs to be zeroed. First make sure the transmitter and receiver are correctly zeroed and the transmitter is held on 0 degrees during adjustment. Connect as shown on Figure 142. If the receiver shaft moves when jumper A is connected from S1 to S3, the transmitter is not on 0 degrees and must be rechecked.

b. Set the unit, whose position the TDX transmits, accurately in the zero or reference position. Unclamp the differential and turn it until the receiver dial reads 0 degrees. The differential is now approximately on electrical zero.

c. Connect jumper B as shown on Figure 142, momentarily between receiver terminals S1 and S3, and differential terminals R1 and R3. If the receiver shaft moves when jumper B is connected, the differential is not on 0 degrees. Rotate the differential slightly and try again. When the differential is zeroed, clamp it in position and remove the jumpers.

10.3.8 Zeroing a torque differential receiver whose rotor is free to turn. When a TDR's rotor is not free to turn, it is necessary to use one of the methods described previously for a torque or control differential transmitter; but when the rotor is free to turn, the units may be connected as shown on Figure 143. The procedure to follow then is given below.

a. Disconnect all other leads from the differential.

b. Connect as shown on Figure 143(A). The rotor will turn to either 0 or 180 degrees when a jumper (shown by the dotted line) is connected. If the meter reads about 28 volts (6 volts for 26-volt synchros), the differential is on approximate electrical zero; proceed to step c. If the meter reads about 156 volts (20 volts for 26-volt units), the synchro is on 180 degrees; disconnect the jumper, turn the rotor to 180 degrees and reconnect the jumper for approximate zero setting.

c. Change the connections to agree with those shown on Figure 143(B).

d. Rotate the synchro until the meter reading is minimum.

10.3.9 Zeroing a differential receiver using two zeroed transmitters. When a differential receiver is installed and cannot be easily disconnected, the following procedure may be used:

a. Be sure both transmitters are zeroed and set in their zero or reference positions.

b. Connect temporary jumpers as shown on Figure 144.

c. With the jumpers connected, unclamp the differential and adjust so the dial on the TDR reads zero or the reference value. After zeroing, clamp the differential and remove jumpers. If the differential receiver moves when the jumpers are connected, the transmitter on that side is not set at 0 degrees and should be rechecked.

10.3.10 Zeroing a control transformer using an AC voltmeter. Using a voltmeter with a 0- to 250-volt and 0- to 5-volt scale, control transformers may be zeroed as follows:

a. Remove connections from control transformer and reconnect as shown on Figure 145(A).

b. Turn rotor or stator to obtain minimum voltage reading.

c. Reconnect meter as shown on Figure 145(B) and adjust rotor or stator for minimum reading.

d. Clamp the control transformer in position and reconnect all leads for normal use.

10.3.11 Using 115 volts instead of 78 volts for zeroing. By exercising proper caution, it is possible to perform the preceding zeroing procedures using 115 volts where a source of 78 volts is not available.

*** CAUTION ***

If 115 volts is applied instead of 78 volts, do not leave the synchro connected for more than 2 minutes or it will overheat and may be permanently damaged.

For 26-volt units, 15 volts may be used instead of 10.2 volts. The same caution regarding the length of time should still apply in order not to damage the unit.

10.4 Summary.

10.4.1 Zeroing methods. The described zeroing methods apply to all standard synchros and pre-standard Navy synchros. The same general methods may be applied to similar units, such as the IC units described in section 12. Connections should be changed when necessary to agree electronically with those shown here, and voltages should be changed when necessary to match the characteristics of the unit that is zeroed.

10.4.2 Checks before zeroing. Before testing a new installation and before hunting trouble in an existing system, be certain all units are zeroed. Also, be sure the device's mechanical position corresponding to electrical zero position is known before trying to zero the synchros. The mechanical reference position corresponding to electrical zero varies from one system to another; therefore, it is suggested that the instruction books and other pertinent information be carefully read before attempting to zero a particular synchro system.

11. SYNCHRO TROUBLES

11.1 Handling. Synchro units require careful handling at all times. **NEVER** force a synchro into place, **NEVER** drill holes into its frame, **NEVER** use pliers on the threaded shaft, and **NEVER** use force to mount a gear or dial on the shaft.

11.2 Maintenance. Two basic rules should be applied:

a. IF IT WORKS, LEAVE IT ALONE.

b. IF IT GOES BAD, REPLACE IT.

Synchros are not expected to operate forever without repair or overhaul, but like other precision instruments, they require the care of a specialist. Unless you are a trained, competent, synchro technician, **NEVER** take a unit apart or try to lubricate it.

11.3 Troubleshooting synchro systems.

11.3.1 General. Shipboard synchro troubleshooting is limited to determining whether the trouble is in the synchro, or in the system connections. You can make repairs in the system connections, but if something is wrong with the unit, replace it. Generally, there are two major categories of trouble occurring in synchro systems. These are: (1) those likely to occur in new installations, and (2) those likely to occur after the system has been in service awhile.

11.3.2 New installations. In a newly installed system, the trouble probably is the result of improper zeroing or wrong connections. Make certain all units are zeroed correctly; then check the wiring. Do not trust the color coding of the wires; check them with an ohmmeter. A major source of trouble is improper excitation. The entire system must be energized from the same phase of the same power source for proper operation.

11.3.3 Existing installations. In systems which have been working, the most common trouble sources are:

a.	Switches	shorts, opens, grounds, corrosion, wrong connections.
b.	Nearby equipment .	water or oil leaking into the synchro from other devices. If this is the trouble, correct it before installing a new synchro.
c.	Terminal boards. .	loose lugs, frayed wires, corrosion, and wrong connections.
d.	Zeroing	units improperly zeroed.

Wrong connections and improper zeroing in any system are usually the result of careless work or inadequate information. Do not rely on memory when removing or installing units. Refer to the applicable instruction book or standard plan. Tag unmarked leads or make a record of the connections; someone else may need the information.

11.3.4 Trouble indicators. Most synchro systems involve units which are in widely separated locations. If trouble occurs in such a system, it must be localized as quickly as possible. To save time, use overload indicators and blown fuse indicators located on a central control board to locate a faulty unit.

11.3.4.1 Overload indicators. The current in the stator circuit of a torque system gives a better indication of mechanical loading than does the current in the rotor circuit. On Figure 146(A), the TR load is such that its rotor lags 30 degrees behind the TX shaft. The rotor current, normally 0.6 ampere, has increased only slightly. The stator current, however, has increased from its normal zero value to 0.5 ampere.

11.3.4.1.1 Overload indicator in TX-TR system. Figure 146(B) shows an overload indicator connected in a simple TX-TR system. Because it is possible, regardless of overload, for the stator current in any one lead to be zero, it is necessary to connect the overload indicator to respond to the currents in at least two stator leads. Two transformers, each having a primary consisting of a few turns of heavy wire and a secondary consisting of many turns of fine wire, are connected as shown. The voltage across each secondary depends on the current in the primary. The voltage from A to B depends on the S1 current, the voltage from B to C depends on the S3 current, the voltage applied to the lamp is determined by the difference in these two currents. The difference between the currents is determined by the difference in the TX and TR positions, not by the actual position. By holding the TR shaft and turning the TX shaft, the graph shown on Figure 147 may be plotted. In this example, the lamp lights when the difference between rotor positions exceeds about 18 degrees. The two transformers are usually mounted in the same case, and provided with taps so they may be used with different types of synchros.

11.3.4.2 Blown fuse indicator. It is common practice to protect TX, CX, and TR units with fuses in their rotor circuits. In the event of severe mechanical overload or shorted windings, these fuses blow out and open the circuit. When this happens, the overload indicator may not give an indication of trouble. As the name implies, a blown fuse indicator lights when a fuse blows out. The following paragraphs describe some examples of blown fuse indicators.

a. Figure 148 shows a simple type of blown fuse indicator: neon lamps connected in parallel with the fuses. When a fuse blows, the voltage across it lights the corresponding lamp. A disadvantage to this arrangement is that, if the leads to the lamp are accidentally shorted, the synchro will be disabled.

b. Figure 149 shows another type of blown fuse indicator: a small transformer having two identical primaries and one secondary connected as shown. When the fuses are closed, the equal primary currents induce equal and opposite voltages in the secondary. These two voltages cancel and the lamp remains unlit. When either fuse blows, no current flows in primary #2; and the voltage induced in primary #1 appears across the lamp, which lights. An added advantage is that only one lamp is required.

c. One trouble common to all blown fuse indicators is illustrated on Figure 150. The TR's rotor circuit has been opened by a blown fuse, stator current flows because the voltages are no longer balanced, and about 85-90 volts are induced in the TR rotor. With only 15-20 volts across the open fuse, the blown fuse indicator does not light. The stator currents cause the overload indicator to light; thus, a blown fuse causes an overload indication. If the switch in the TX rotor circuit is opened, the blown fuse indicator lights and shows the actual location of the trouble.

11.3.5 Some symptoms and their probable cause. Tables XXX through XXXV summarize, for a simple TX-TR system, some symptoms and their probable causes. When two or more receivers are connected to one transmitter, similar symptoms occur. If all the receivers act up, the trouble is in the transmitter or the main bus. If the trouble appears in one receiver only, check that unit and its connections. The angles shown do not apply to systems using differentials, or to systems whose units are incorrectly zeroed. Always check the system zeroing before looking for other troubles.

11.3.5.1 Control system problems. In a control system, the trouble may be slightly more difficult to isolate. The existence of trouble is readily indicated when the system does not properly respond to the input order. For control systems, it is easiest to locate troubles by use of the Synchro Tester, Mk 2 All Mods, or by checking the operating voltages.

11.3.6 Trouble from other equipment. Do not connect other equipment, which is not related to the synchro system, to the primary excitation bus. When unrelated equipment is connected to the primary excitation bus, the system will show all the symptoms of a shorted rotor when it is turned on. However, it will check good when it is turned off. On Figure 151, the rotor of the TR is connected in parallel with other equipment, and both are fed normally from the AC supply through switch SW2. If this switch is opened while switch SW1 is still closed, the equipment connected across the TR rotor acts as a partial short, causing overheating of both units.

11.3.7 Checking standard voltages. A good way to find the trouble in an operating system is to use known operating voltages as references for faulty operation. Since the proper operation of a system is indicated by the proper variations in rotor and stator voltages, an AC voltmeter can be used to locate troubles. When an AC voltmeter is connected between any two stator leads, the voltage should vary from 0 to 90 volts (0 to 11.8 volts for 26-volt systems) as the transmitter rotates. The zero and maximum voltage values should occur at the following headings:

METER CONNECTED BETWEEN	ZERO VOLTAGE HEADINGS	MAXIMUM VOLTAGE HEADINGS
S1 and S2	120°,300°	30°,210°
S2 and S3	60°,240°	150°,330°
S1 and S3	0°,180°	90°,270°

The rotor voltage should remain constant at all times, either 115 volts or 26 volts. In a system where the units are close enough to permit checking, the voltage between the R1 or R2 terminal of any unit energized by the primary AC source and the corresponding R1 or R2 terminal of any other unit energized by the primary AC source should be zero. Where the excitation voltage of 115 volts or 26 volts is above or below the required value ±1 percent, the maximum stator voltages will also be above or below normal.

11.3.8 Voltage balance check. To check the voltage balance of a torque transmitter, connect a good receiver whose shaft is free to turn, as shown on Figure 152. If the output voltages are correctly balanced, the voltmeter will not vary more than a volt or so as the shaft of the TX or TDX is turned through 360 degrees. Any greater variation indicates an unbalance, possibly due to a faulty synchro capacitor or leakage between two of the three wires.

*** CAUTION ***

The voltage balance check produces high currents in the receiver. Disconnect the receiver as soon as the test is completed.

11.3.9 Use of 60-hertz Synchro Tester, Mk 33 Mod 0. The 60-hertz Synchro Tester, Mk 33 Mod 0 (Figures 153 and 154), may be used to reduce the time required to locate defective units using 115-volt, 60-hertz current only. The synchro tester consists of a 15TRX6A receiver on which a calibrated dial is mounted and may be used either as a TR, TX, or CX.

11.3.9.1 The synchro tester used as a TR. When used as a TR, the synchro tester is connected in place of the TR suspected of being defective or connected directly to the TX or TDX to check its output. The calibrated dial on the synchro tester should follow the rotation of the transmitter. The synchro tester may also be used for a quick check of whether or not the transmitter is on an approximate electrical zero.

11.3.9.2 The synchro tester used as a transmitter. When a transmitter or differential transmitter in the system between the transmitter and CT is suspected of being defective, the synchro tester may be used to simulate the action of the transmitter. Used as a control transmitter, the synchro tester drives one of any 60-hertz type standard or pre-standard synchro control transformers. The synchro tester may be used as a torque transmitter for driving one 18TR6, 23TR6, 1F or 1HF torque receiver.

11.3.9.3 Other uses of the synchro tester. The synchro tester will help locate defective units, but should not be relied on without question for use in zeroing units. It is possible for the calibrated dial to slip from its proper position. Also, since the dial is graduated only every 10 degrees, it is difficult to read small angles with accuracy. The synchro tester is often used in testing range data transmission systems. As an example, a change in range data of 10,000 yards may cause the synchro tester to turn through 90 degrees, 180 degrees, or some other definite angle. Depending upon the ingenuity of the user, the synchro tester should prove to be a useful and timesaving device.

11.3.9.4 Synchro tester for 400-hertz units. Synchro Tester Mk 30 All Mods, shown on Figures 155 and 156, is a similar device fabricated with a 15TRX4A synchro, for use in checking 400-hertz synchros.

11.4 Oscillations and spinning in torque systems. Oscillations (rapid swinging back and forth) and spinning are fairly common in torque systems. Spinning is usually caused by a defective inertia damper or shorted stator leads. Excessive oscillations may be due to these same troubles, but the switching oscillations described here are normal in some systems.

11.4.1 Switching oscillations. In systems where one transmitter drives several receivers, switching oscillations may occur when suddenly one receiver is switched into the system. All the receivers in the system oscillate for a few seconds, and then the oscillations die out. Figure 157(A) shows a transmitter connected to two receivers, with a third receiver which can be switched into the system. The transmitter and the two connected receivers are set at 90 degrees. The third receiver is set at zero. At the instant the switch is thrown (Figure 157(B)), a strong torque is exerted on the shaft of TR#3, turning it toward 90 degrees. At the same time, the currents producing this torque produce voltage changes across the stator coils of TR#1 and TR#2. These changes cause the rotors of TR#1 and TR#2 to turn toward zero. How far they turn depends upon the size of the transmitter and the number of units in the system. When TR#3 reaches 90 degrees, the voltages balance and its stator currents are reduced to zero. No torque acts on its shaft, so it continues to rotate to some position beyond 90 degrees. This pulls the other receivers slightly out of position (see Figure 157(C)). When enough torque is built up to stop TR#3, it starts back toward and passes 90 degrees a little slower this time. This operation continues for a few seconds before the system stabilizes. The receiver has to pass the correct position before it can stop. It is often impractical to correct switching oscillations after the system has been installed, but they can be minimized by the following precautions:

a. **NEVER** replace a receiver with a larger receiver. Excessive currents cause switching oscillations. The smallest practical unit should be used in any synchro receiver installation.

b. **NEVER** put too much load on a receiver.

c. **NEVER** replace a transmitter with a smaller unit.

d. **AVOID** long runs of small-diameter wire in connections.

12. SIMILAR DEVICES

12.1 Clarification. Quite often, other electromagnetic data-transfer devices are improperly referred to as synchros. The devices mentioned in this section are described solely to avoid such confusion. Nothing in this section should be taken as a suggestion that the units described here be used in place of synchros.

12.2 Interior communication (IC) units. The Engine Order Telegraph, Steering Telegraph, Rudder Indicator and similar position-indicating systems used on naval vessels are usually simple synchro systems. However, many ships use IC transmitters and IC receivers for the transfer of such information. IC units operate on the same general principles, but enough differences exist to warrant a brief comparative discussion.

12.2.1 Construction. Because of their construction, IC units are sometimes called reversed synchros. The primary winding, consisting of two series-connected coils, is mounted physically on the stator. The secondary, consisting of three Y-connected coils, is mounted physically on the rotor. Figure 158 shows this arrangement schematically.

12.2.2 Operation. IC units operate on the same principles of interacting magnetic fields as synchros, but differ in direction of shaft rotation and amount of torque obtainable. When an IC transmitter and IC receiver are connected in parallel (Figure 159(A)), the shaft of the IC receiver follows the rotation of the IC transmitter shaft. On Figure 159(B), the IC transmitter is replaced by a synchro transmitter. The IC receiver shaft now turns in a direction opposite to that of the synchro transmitter. Voltages which cause counterclockwise rotation of a synchro shall cause clockwise rotation of an IC unit shaft. An IC receiver can be connected to an IC transmitter so that the shafts rotate in opposite directions (see Figure 159(C)). There is one exception to this: the internal connections of the Bendix type N unit, CAL-4400-I, are arranged so that when it is used with a type A or B IC transmitter, S1-S3 must be crossed for the same rotation and connected directly for opposite rotation. The torque obtainable from either an IC unit or synchro is determined by the magnetizing power, and the magnetizing power which can be applied is limited by the allowable temperature rise. When the stator is energized, as in IC units, the magnetizing power can be increased with a resulting larger torque. The reason for this is that the losses are dissipated in the form of heat around the outer shell of the IC transmitter or receiver. In synchros, this heat loss is dissipated through the rotor, the air gap, and then the outer shell to the surrounding air.

12.2.2.1 Disadvantage of IC. The main disadvantage of IC units lies in possible inaccuracy with erratic operation at small error currents. The output currents are taken from the rotor and must pass through slip rings and brushes, which often become dirty and offer a high resistance to these small currents.

12.2.2.2 IC characteristics. Tables XXXVI through XXXVIII list the important characteristics of various IC units. For purposes of comparison, equivalent synchros are also listed. The primary supply for all units listed in the tables is 115 volts, 60 hertz.

12.2.3 Zeroing IC units. To zero an IC unit, apply the general theory used for synchros. The position where rotor coil #2 lines up with the stator coils is defined as electrical zero.

a. To zero an IC receiver:

(1) Mount the receiver in its normal position and disconnect all external leads.

(2) Connect as shown on Figure 160. The shaft will turn to the electrical zero position.

*** CAUTION ***

Do not leave the receiver connected in this manner any longer than necessary, as it will overheat.

(3) Loosen the shaft coupling or the clamps on the stator and rotate either one until the indicator points to the zero reading.

(4) Tighten in this position and reconnect for normal use.

b. To zero an IC transmitter:

(1) Mount the transmitter in its normal position and set the unit whose position it transmits in the zero or reference position.

(2) If the transmitter shaft coupling can be loosened:

(a) Disconnect all external leads and connect the transmitter as shown on Figure 160.

(b) With the shaft held in the zero position, tighten the shaft coupling and reconnect for normal operation.

(3) If the IC transmitter shaft coupling cannot be loosened:

(a) Zero one receiver in the system, as described previously.

(b) Adjust the position of the transmitter's stators, or the linkage connecting its shaft to the associated equipment, until the zeroed receiver indicates zero.

(c) Tighten the unit in this position.

The physical reference position of an IC unit corresponding to electrical zero varies as indicated here, depending on its use. Instruction books should still be referred to since there may be some exceptions to these rules.

APPLICATION	PHYSICAL POSITION FOR ELECTRICAL ZERO
Engine Order Telegraph	Center of Stop Order
Steering Telegraph	Zero
Rudder Indicator	Zero
Propeller Revolution Telegraph	Zero
Underwater Log	Zero
Wind Direction and Intensity	Zero

12.2.4 IC unit troubles. The troubleshooting tables for synchros in section 11 may be applied to IC units if the following changes are made: substitute rotor for stator, stator for rotor, R1 for S1, R2 for S2, S1 for R3, S2 for R2, and S3 for R1.

a. Some typical troubles of IC units are summarized here. If the receiver follows, but reads wrong:

(1) Make certain all units are correctly zeroed.

(2) Check interconnections to be certain they are correct.

(3) If the reading is sometimes correct and sometimes 180 degrees out, suspect an open in the receiver or transmitter stator circuit.

(4) If the indicator follows correctly for certain transmitter positions, but is sloppy and oscillates in other positions, suspect an open in the rotor circuits.

(5) If fuses are blown and the indicator reads 90 degrees off, suspect a shorted stator.

(6) If one receiver of a multiple system is damaged, the rest will read wrong.

b. If the receiver does not follow when the transmitter is turned:

(1) Turn the receiver by hand to be sure it isn't jammed; other receivers in the same system will read wrong if it is.

(2) Check the AC supply to stators.

(3) Check for two open rotor connections.

(4) There may be a short between two rotor leads. In this case, all indicators in the system are held on some multiple of 60 degrees.

c. If the receiver swings violently back and forth or spins, although sometimes caused by sudden changes in position or switching operations, this may indicate trouble:

(1) Stop it by hand.

(2) If it follows correctly and reads correctly until it gets a sudden shock which starts it spinning or oscillating again, the damper mounted on its shaft is not operating properly.

(3) If it locks in at a certain position and holds there regardless of the transmitter position, two rotor leads are shorted together and the damper may also be bad.

(4) If it shows no tendency to lock in or to follow, but just spins, all three rotor leads are probably shorted together.

12.2.5 IC unit maintenance. Unlike synchros, necessary maintenance on IC units can be performed by qualified shipboard technicians. Rotor assemblies may be taken apart for maintenance, provided extreme care is exercised. Disassembly instructions should be read carefully before attempting to disassemble any unit. Some assemblies are carried in spares if needed. Where qualified personnel are not available, no attempt should be made to repair units.

12.2.5.1 Unit repair. If trouble develops in the rotor circuits, remove the cover over the brushes, the nameplate on Henschel units, and inspect the brushes and slip rings. If they are corroded or dirty, remove the brushes and clean the brushes and slip rings. Use a clean, lint-free cloth or chamois. In cases of severe corrosion or pitting, very fine sandpaper may be used on the slip rings.

12.2.5.1.1 Disassembling the unit. If it is necessary to replace the rotor, or if the unit needs oiling, the unit must be taken apart. Remove the brushes and the screws which hold the unit together; pull it apart carefully and remove the rotor. Inspect the ball bearings to be sure they are in good condition, and replace them from spares if necessary. Before installing new bearings, clean off the thick vaseline used to prevent rust. When replacing a bearing in the front end frame, do not disturb the shims. Four shims are usually needed, allowing an end play of 0.01 to 0.015 inch. If oil is needed on the bearing, apply one drop at the top of each ball, or less if the balls are oily. Use a high-grade light oil as recommended by the manufacturer. Standard Oil of New Jersey, Univis No. 48, or watch oil may be used as a substitute. Clean the oscillation damper thoroughly, covering the rubbing surfaces with a light film of vaseline, before reassembling the unit.

12.2.6 Interchangeability of IC units and synchros. Tables XXXVI through XXXVIII indicate that BuShips IC units of any given type are interchangeable for most applications as complete units, both mechanically and electrically. This holds true regardless of manufacturer or date of manufacture with the following exceptions:

a. Henschel and Bendix Type N units are electrically interchangeable, but considerably different as to mounting dimensions.

b. Type A and type M units have been supplied with both 0.3125-inch diameter and 0.25-inch diameter shafts. When adapting the 0.3125-inch type units to instruments formerly equipped with 0.25-inch units, the following should be noted:

(1) If a 0.25-inch diameter shaft was used in conjunction with a shaft extension or coupling with a thin cross section, make a new extension or coupling to fit the 0.3125-inch diameter shaft.

(2) If a 0.25-inch diameter shaft was used in connection with gears, hubs, clamping nuts, shaft extensions, couplings, pointer hubs, or throw collars having an adequate cross section, ream a larger hole to fit the larger 0.3125-inch shaft. It is not recommended that the 0.3125-inch diameter shaft be ground down to 0.25 inch.

c. Some applications of Henschel 15-001 units require a 4-48 screw through the end of the shaft. Henschel 15-021 units have a 6-40 screw. This applies particularly to the type A unit used in Pitometer Log Corporation type B shaft revolution transmitters.

d. Type A and type M outside shell diameter variation, as listed in the tables, is not serious and does not affect interchangeability for most applications.

e. Under normal conditions, synchros should never be used to replace IC units. Adequate spares are normally provided for all IC units installed on naval vessels. However, in an emergency, IC units may be interchanged to the extent indicated in the table. The following notes will be helpful in emergency replacement of IC units with corresponding synchros:

(1) Mounting dimensions are essentially the same except for Henschel type N units.

(2) Some form of adapter must be used in practically all cases, as shaft diameters and methods of shaft coupling differ considerably.

(3) Shaft rotation is opposite for IC units and synchros. Ic units are electrically interchangeable with corresponding synchros provided terminals R1, R2, S1, S2, S3 of synchros, respectively, are connected where terminals S1, S2, R3, R2, R1 of Ic units were connected. The primary is on the stator of IC units and on the rotor of synchros.

(4) Synchros have higher accuracy than corresponding IC units.

(5) All IC units are equipped with terminal blocks, but all synchros are not. However, this does not affect interchangeability.

More complete instructions concerning the details of synchro adaptation are contained in Buships standard drawings, available to interested activities.

12.3 Commutator transmitter. Another device is the AC commutator transmitter, shown on Figure 161 whose construction is similar to a transformer. A single-layer secondary is wound on the flat side of an iron core. Three brushes, mounted on a common shaft and spaced 120 degrees apart, are rotated around an uninsulated circular path in continuous contact with the windings. AC excitation is applied to the primary winding and the output taken from the three brushes. Commutator transmitters, while not extensively used, have certain advantages over synchro transmitters, especially in the larger sizes. These advantages are: (1) greater accuracy, and (2) a higher coupling coefficient between primary and secondary. For a higher degree of accuracy, it is necessary that the pitch of the secondary windings be uniform and the wire size be sufficiently fine to avoid graininess.

12.4 Stepping motor system. The synchros and similar devices thus far discussed are used with alternating currents. At times, remote indicating systems which operate on direct current are required. One of these is the stepping motor system illustrated on Figure 162. Although many variations are employed, the system shown is typical. The stepping motor system is often used to drive compass repeaters on naval vessels and merchant ships having DC power. The system operates directly from a DC supply and requires no AC excitation.

12.4.1 Operation. The principles of operation of the stepping motor are very much the same as those discussed in section 1. Six electromagnets are mounted around a soft iron armature and connected as shown on Figure 163. Each pair of coils is wound opposite to the adjacent pair. If a DC voltage is applied across the number 1 coils, the armature turns to the position shown on Figure 164(A). Since the armature is soft iron, either end may turn up, depending upon the position of the rotor when voltage is applied. If the same voltage is also applied to the number 2 coils, the armature turns to a position midway between the number 1 and number 2 coils (Figure 164(B)). If the number 1 coils are now disconnected, the armature turns until it lines up with the number 2 coils (Figure 164(C)). Figure 164(D) shows the number 3 coils connected and the armature rotated one step further. If this process is continued, Figures 164(E) and 164(F), the armature can be rotated through 360 degrees.

12.4.1.1 Operation by rotary switch. In actual operation, the stepping motor is driven by a rotary switch shown in Figure 165. As the switch rotates, it applies voltage first to coil 1, then to 1 and 2 together, then to coil 2, then to coils 2 and 3 together, then to coil 3 and so on until the complete revolution is made. As a result, the armature turns in 30-degree steps following the rotation of the rotary switch. The rotating arm of the switch is geared to the gyro compass so that 1-degree rotation of the gyro causes the rotary arm to rotate through 360 degrees. The stepping motor is geared to its compass card so that the card moves one degree for each six steps of the motor. There are two stepping motor systems in use, the only difference being the voltage supplied to the motor coils. The older system operates on 20 volts, the newer one on 70 volts.

Typical diagrams of these systems are shown on Figure 165.

12.4.2 Repeaters. A hand reset knob is provided on stepping motor repeaters, so that the motor can be turned by hand to agree with the reading on the master compass each time the power supply is reconnected. The reason for this is that there are two positions on the motor where the armature can lock in, giving an erroneous reading on the compass repeater.

12.4.3 Conversion of stepping motor to synchro receiver. There are times when synchro receivers must be used on a vessel which has a stepping motor system, and in these cases, a converter a necessary. Figure 166(A) shows a simple stepping motor to synchro converter. A coupling connects the shafts of the synchro transmitter and stepping motor. The converter receives stepping motor transmission from the gyro compass system and transmits synchro signals to systems requiring compass information. The wiring diagram of the converter is shown on Figure 166(B).

12.4.4 Zeroing a stepping motor to synchro converter. To zero a stepping motor to synchro converter, proceed as follows:

a. Make certain all the associated synchro receivers are properly zeroed.

b. Remove excitation from the stepping motor.

c. Set the synchro transmitter on electrical zero and adjust the attached scale to read zero.

d. Set the shaft of the stepping motor by hand so that the scale reading agrees with the reading of the master compass, and reconnect the stepping motor to the system.

12.5 DC position indicator. Another device operating on DC current is the position indicator shown on Figure 167. In construction, the transmitter is a potentiometer with 360 degrees of continuous rotation. The winding is tapped every 120 degrees and the DC excitation is applied to two brushes spaced 180 degrees apart. If voltages AB, BC, and CA are plotted against the shaft angle, a set of curves similar to those of a synchro is obtained. The receiver is similarly wound with the windings tapped every 120 degrees. Inserted within the receiver windings is a cylindrical or salient pole permanent magnet which is free to rotate and turn a shaft. Since alternating currents are not present in this system, a stationary copper damping ring or cup is usually mounted in the air gap between the rotor and pole pieces.

TABLE I. Synchro functional classifications.

FUNCTIONAL CLASSIFICATION	MILITARY ABBREVIATIONS	INPUT	OUTPUT
Torque Transmitter	TX	Rotor positioned mechanically or manually by information to be transmitted	Electrical output from stator identifying rotor position supplied to torque receiver, torque differential transmitter, or torque differential receiver.
Control Transmitter	CX	Same as TX	Electrical output same as TX but supplied only to control transformer or control differential transmitter
Torque Differential Transmitter	TDX	TX output applied to stator; rotor positioned according to amount data from TX must be modified	Electric output from rotor (representing angle equal to algebraic sum or difference of rotor position angle and angular data from TX) supplied to torque receivers, another TDX, or a torque differential receiver
Control Differential Transmitter	CDX	Same as TDX but data usually supplied by CX	Same as TDX but supplied only to control transformer or another CDX
Torque Receiver	TR	Electrical angular position data from TX or TDX supplied to stator	Rotor assumes position determined by electrical input supplied
Torque Differential Receiver	TDR	Electrical data supplied from two TDX's, two TX's or one TX and one TDX (one connected to rotor and one to stator)	Rotor assumes position equal to algebraic sum or difference of two angular inputs
Control Transformer	CT	Electrical data from CX or CDX applied to stator. Rotor positioned mechanically or manually	Electrical output from rotor (proportional to sine of the difference between rotor angular position and electrical input angle)
Torque Receiver	TRX	Depending on application, same as TX	Depending on application, same as TX or TR

TABLE II. Standard capacitor boxes.

MARK	MOD	CAPACITOR TYPE	QUANTITY
1	0	1C, MK 12	2
2	0	2C, MK 13	2
3	0	3C, MK 1	2
4	0	9C, MK 3	2
5	0	15C, MK 4	2
2	1	4C, MK 14	2

TABLE III. Special types of capacitor boxes, "Synchro Exciter Assemblies".

MARK	MOD	CAPACITOR TYPE	QUANTITY
14	0	9C, MK 3	4
15	0	3C, MK 1	1
16	0	3C, MK 1	2
18	0	3C, MK 1	3
19	0	3C, MK 1	1
		9C, MK 3	1
		3C, MK 1	2
24	0	9C, MK 3	3
25	0	9C, MK 3	2
26	0	9C, MK 3	4
27	0	3C, MK 1	1
28	0	9C, MK 3	1

TABLE IV. Characteristics of standard synchro capacitors.

TYPE	MARK	FOR USE WITH	TOTAL CAP.	CAP. PER LEG	CAPACITY BETWEEN TERMINALS	CURRENT AMPS (see above)	WT. LBS
1C	12	1CT MOD 3A 1CT MOD 2 1CT MK 5 STD. 5CT MK 3 STD. 5HCT MK 6 STD 5CT MK 1 MOD 4 5CT MK 4 MOD 4	1.8	.6	.9	.035	1
2C	13	5CT MK 1 MOD 3	4.2	1.4	2.1	.082	2
3C	1	5D, 5DG	30.0	10.0	15.0	.59	6
4C	14	1DG MK 1 MOD 1 1CT MOD 3	9.0	3.0	4.5	.176	
9C	3	6DG	90.0	30.0	45.0	1.76	16
15C	4	7DG	150.0	50.0	75.0	2.94	25

THE FOLLOWING TYPES OF CAPACITORS SHOULD BE USED ONLY AS REPLACEMENTS

TYPE	MARK	SUPERSEDED BY TYPE	TOTAL CAP.	CAP. PER LEG	CAPACITY BETWEEN TERMINALS	WT. LBS
3CE	5	3C	30	10	15	7
6CE	6	6C	60	20	30	14
9CE	7	9C	90	30	45	21
15CE	8	15C	150	50	75	33
30C	9	—	—	—	—	—
9CX	10	—	90	30	45	19
2.25CX	11	—	—	—	—	6.25
6C	2	—	60	20	30	11

TABLE V. Limiting loads for MIL-S-20708 synchros in 400-hertz Torque System A (Figure 59).

TRANSMITTER	LIMITING NUMBER OF TR (OR TRX) UNITS		
	18TR4B or 18TRX4A or	23TR4B or 23TRX4A or	31TR4D 31TRX4A
18TRX4A	2	—	—
23TRX4A	5	2	—
31TRX4A	13	5	2
37TRX4A	18	7	3
78V-18TDX4C	1	—	—
78V-23TDX4C	3	1	—

TABLE VI. Limiting loads for MIL-S-20708 synchros in 400-hertz Torque System B (Figure 59).

	DIFFERENTIALS		LIMITING NUMBER OF TR's OR TRX's PER TDX (n_b/n_d)		
TRANSMITTER	QUANTITY (n_d)	TYPE	18TR4B 18TRX4A or	23TR4B 23TRX4A or	31TR4D 31TRX4A
23TRX4A	1 to 2	18TDX4C	1	—	—
23TRX4A	1	23TDX4C	2	—	—
23TRX4A	2	23TDX4C	1	—	—
31TRX4A	1 to 5	18TDX4C	1	—	—
31TRX4A	1	23TDX4C	3	1	—
31TRX4A	2	23TDX4C	2	1	—
31TRX4A	3	23TDX4C	2	—	—
31TRX4A	4 to 6	23TDX4C	1	—	—
37TRX4A	1 to 7	18TDX4C	1	—	—
37TRX4A	1 to 2	23TDX4C	3	1	—
37TRX4A	3	23TDX4C	2	1	—
37TRX4A	4 to 5	23TDX4C	2	—	—
37TRX4A	6 to 8	23TDX4C	1	—	—
78V-23TDX4C	1	18TDX4C	1	—	—
78V-23TDX4C	1	23TDX4C	2	—	—

TABLE VII. Limiting loads for MIL-S-20708 synchros in 400-hertz Torque System C (Figure 59).

TRANS-MITTER	LOAD 1 LIMITING NUMBER OF TR's (OR TRX's)			LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF TR's (OR TRX's)		
	18TR4B or 18TRX4A	23TR4C or 23TRX4A	31TR4D or 31TRX4A	QUANTITY (n_d)	TYPE	18TR4B or 18TRX4A	23TR4B or 23TRX4A	31TR4D or 31TRX4A
23TRX4A	—	—	—	1 to 2	18TDX4C	1	—	—
23TRX4A	1	—	—	1	23TDX4C	2	—	—
23TRX4A		—	—	1	23TDX4C	1	—	—
23TRX4A		—	—	2	23TDX4C	1	—	—
23TRX4A	1	—	—	2	23TDX4C	1	—	—
31TRX4A		—	—	1 to 5	18TDX4C	1	—	—
31TRX4A	1	—	—	1	18TDX4C	1	—	—
31TRX4A		—	—	1	23TDX4C	3		—
31TRX4A	2	—	—	1	23TDX4C	2		—
31TRX4A	5	2	—	1	23TDX4C	1		—
31TRX4A		—	—	1	23TDX4C		1	—
31TRX4A		—	—	2	23TDX4C	2		—
31TRX4A	1	—	—	2	23TDX4C	2		—
31TRX4A	5	2	—	2	23TDX4C	1		—
31TRX4A		—	—	2	23TDX4C		1	—
31TRX4A		—	—	3	23TDX4C	2	—	—
31TRX4A	4	2	—	3	23TDX4C	1	—	—
31TRX4A			—	4 to 5	23TDX4C	1	—	—
31TRX4A	3	1	—	4 to 5	23TDX4C	1	—	—
31TRX4A		—	—	6	23TDX4C	1	—	—
31TRX4A	2	—	—	6	23TDX4C	1	—	—
37TRX4A		—	—	1 to 7	18TDX4C	1	—	—
37TRX4A	1	—	—	1 to 3	18TDX4C	1	—	—

TABLE VII. Limiting loads for MIL-S-20708 synchros in 400-hertz Torque System C (Figure 59) - Continued.

TRANS-MITTER	LOAD 1 LIMITING NUMBER OF TR's (OR TRX's)			LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF TR's (OR TRX's)		
	18TR4B or 18TRX4A	23TR4C or 23TRX4A	31TR4D or 31TRX4A	QUANTITY (n_d)	TYPE	18TR4B or 18TRX4A	23TR4B or 23TRX4A	31TR4D or 31TRX4A
37TRX4A		—	—	1	23TDX4C	3		—
37TTX4A	3	1	—	1	23TDX4C	2		—
37TRX4A	8	3	1	1	23TDX4C	1		—
37TRX4A		—	—	1	23TDX4C		1	—
37TRX4A		—	—	2	23TDX4C	3		—
37TRX4A	2	—	—	2	23TDX4C	2		—
37TRX4A	7	3	1	2	23TDX4C	1		—
37TRX4A		—	—	2	23TDX4C		1	—
37TRX4A		—	—	3	23TDX4C	2		—
37TRX4A	1	—	—	3	23TDX4C	2		—
37TRX4A	6	2	1	3	23TDX4C	1		—
37TRX4A		—	—	3	23TDX4C		1	—
37TRX4A		—	—	4	23TDX4C	2	—	—
37TRX4A	6	2	1	4	23TDX4C	1	—	—
37TRX4A		—	—	5	23TDX4C	2	—	—
37TRX4A	5	2	—	5	23TDX4C	1	—	—
37TRX4A			—	6 to 7	23TDX4C	1	—	—
37TRX4A	4	2	—	6 to 7	23TDX4C	1	—	—
37TRX4A			—	8	23TDX4C	1	—	—
37TRX4A	3	1	—	8	23TDX4C	1	—	—
78V-23TDX4C	—	—	—	1	18TDX4C	1	—	—
78V-23TDX4C		—	—	1	23TDX4C	2	—	—
78V-23TDX4C	1	—	—	1	23TDX4C	1	—	—

TABLE VIII. Optimum values of synchro capacitors for MIL-S-20708 400-hertz synchro control transformers and differential units.

TYPE	DELTA CONNECTED CAPACITORS FOR POWER FACTOR CORRECTION NOMINAL ± 10% (MICROFARADS)			
	TOTAL CAP.	CAP. PER LEG	CAP. BETWEEN TERMINALS	REMARKS
11CT4E	0.108	0.036**	0.054	Matched to within 1 percent
15CT4C	0.066	0.022	0.033	Matched to within 1 percent
18CT4C	0.042	0.014	0.021	Matched to within 1 percent
23CT4C	0.042	0.014	0.021	Matched to within 1 percent
11CDX4B	0.33	0.11**	0.165	
15CDX4C	0.63	0.21	0.315	Matched to within 1 percent
18CDX4C	0.84	0.28	0.42	Matched to within 1 percent
23CDX4C	1.98	0.66**	0.99	Matched to within 1 percent
18TDX4C	3.00	1.0	1.50	Matched to within 1 percent
23TDX4C	6.30	2.1	3.15	Matched to within 1 percent

**represents average value for previous models and present ones; that is,
for 11CT4E or 11CT4E, use 0.036 microfarad per leg
for 15CDX4-XN or 15CDX4D, use 0.21 microfarad per leg
for 23CDX4-XN or 23CDX4C, use 0.66 microfarad per leg

TABLE IX. Limiting CT loads, additional to torque loads of Table V, for MIL-S-20708 synchros in 400-hertz Mixed System A.

TX IN TORQUE SYSTEM A, TABLE V	LIMITING NUMBER OF CT UNITS ADDITIONAL TO TORQUE LOADS OF TABLE V	
	11CT4E 15CT4C	or 18CT4C 23CT4C
18TRX4A	20	40
23TRX4A	50	100
31TRX4A	150	300
37TRX4A	250	500
78V-18TDX4C	15	30
78V-23TDX4C	30	60

TABLE X. Limiting CT loads, additional to torque loads of Tables VI and VII, for MIL-S-20708 synchros in 400-hertz Mixed System B.

TDX OR TX IN TORQUE SYSTEMS B AND C, TABLES VI AND VII	LIMITING NUMBER OF CT's PER TR OR TRX (n_{ct}) ADDITIONAL TO TORQUE LOADS OF TABLES VI AND VII	
	11CT4E 15CT4C	or 18CT4C 23CT4C
18TRX4A	3	6
23TRX4A	7	14
31TRX4A	19	38

TABLE XI. Limiting CDX-CT loads that replace a TDX-TR branch of Tables VI and VII for MIL-S-20708 synchros in 400-hertz Mixed System C.

TDX-TR BRANCH IN TORQUE SYSTEMS B AND C, TABLES VI AND VII	NUMBER AND TYPE OF CDX UNITS REPLACING ONE TDX-TR BRANCH		CT UNITS PER CDX	
	NUMBER	TYPE	11CT4C or 15CT4B	18CT4B or 23CT4B
18TDX4C with its TR load	1 to 4	11CDX4B	1	2
18TDX4C	1 to 2	15CDX4C	2	4
18TDX4C	1	18CDX4C	6	12
18TDX4C	2	18CDX4C	2	4
18TDX4C	1	23CDX4C	2	4
23TDX4C with its TR load	1 to 7	11CDX4B	1	2
23TDX4C	1 to 4	15CDX4C	2	4
23TDX4C	1 to 2	18CDX4C	6	12
23TDX4C	3	18CDX4C	3	6
23TDX4C	4	18CDX4C	1	2
23TDX4C	1	23CDX4C	14	28
23TDX4C	2	23CDX4C	2	4

TABLE XII. Limiting loads for MIL-S-20708 synchros in 400-hertz Control System A (Figure 60).

TRANSMITTER	LIMITING NUMBER OF CT UNITS 11CT4E 15CT4C	OR 18CT4C 23CT4C	DROP IN VOLTAGE GRADIENT OF CT (%)
11CX4E	2	4	11
15CX4D	7	14	10
18CX4D	17	34	10
23CX4D	35	70	10
78V-11CDX4B	2	4	11
78V-15CDX4D	3	6	10
78V-18CDX4C	10	20	10
78V-23CDX4C	25	50	10

TABLE XIII. Limiting loads for MIL-S-20708 synchros in 400-hertz Control System B (Figure 60).

TRANSMITTER	DIFFERENTIAL		LIMITING NUMBER OF CT's PER CDX (n_{ct}/n_{cdx})		DROP IN VOLTAGE GRADIENT OF CT (%)
	QUANTITY	TYPE	11CT4D 15CT4C	OR 18CT4C 23CT4C	
15CX4D	1	11CDX4B	1	2	11
15CX4D	1	15CDX4D	—	1	11
18CX4D	1	11CDX4B	1	3	10
18CX4D	2	11CDX4B	1	2	11
18CX4D	3	11CDX4B	—	1	10
18CX4D	4	11CDX4B	—	1	11
18CX4D	1	15CDX4D	2	4	10
18CX4D	2	15CDX4D	—	1	10
18CX4D	1	18CDX4C	4	8	10
18CX4D	2	18CDX4C	1	2	10
23CX4D	1	11CDX4B	1	3	10
23CX4D	2	11CDX4B	1	3	10
23CX4D	3	11CDX4B	1	2	10
23CX4D	4	11CDX4B	1	2	10
23CX4D	5	11CDX4B	1	2	11
23CX4D	6	11CDX4B	—	1	9
23CX4D	7	11CDX4B	—	1	10
23CX4D	1	15CDX4D	3	6	10
23CX4D	2	15CDX4D	2	4	10
23CX4D	3	15CDX4D	1	3	10
23CX4D	4	15CDX4D	—	1	9
23CX4D	5	15CDX4D	—	1	10
23CX4D	1	18CDX4C	7	14	10
23CX4D	2	18CDX4C	4	8	10
23CX4D	3	18CDX4C	2	4	10
23CX4D	4	18CDX4C	1	2	10
23CX4D	1	23CDX4C	9	18	10
23CX4D	2	23CDX4C	2	4	10
78V-18CDX4C	1	11CDX4B	1	2	10
78V-18CDX4C	2	11CDX4B	—	1	10
78V-18CDX4C	1	15CDX4D	1	2	10

TABLE XIII. Limiting loads for MIL-S-20708 synchros in 400-hertz Control System B (Figure 60) - Continued.

TRANSMITTER	DIFFERENTIAL QUANTITY	DIFFERENTIAL TYPE	LIMITING NUMBER OF CT's PER CDX (n_{ct}/n_{cdx}) 11CT4D 15CT4C	OR 18CT4C 23CT4C	DROP IN VOLTAGE GRADIENT OF CT (%)
78V-23CDX4C	1	18CDX4C	1	3	10
78V-23CDX4C	1	11CDX4B	1	3	10
78V-23CDX4C	2	11CDX4B	1	2	10
78V-23CDX4C	3	11CDX4B	1	2	11
78V-23CDX4C	4	11CDX4B	—	1	10
78V-23CDX4C	5	11CDX4B	—	1	10
78V-23CDX4C	1	15CDX4D	2	5	10
78V-23CDX4C	2	15CDX4D	1	2	10
78V-23CDX4C	3	15CDX4D	—	1	10
78V-23CDX4C	1	18CDX4C	5	10	10
78V-23CDX4C	2	18CDX4C	2	4	10
78V-23CDX4C	3	18CDX4C	—	1	10
78V-23CDX4C	1	23CDX4C	5	10	10

TABLE XIV. Limiting loads for MIL-S-20708 synchros in 400-hertz Control System C (Figure 60).

	LOAD 1 LIMITING NUMBER OF CT UNITS		LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF CT's PER CDX (n_{ct}/n_{cdx})		DROP IN VOLTAGE GRADIENT FOR CT's IN LOAD 2 (%)
TRANSMITTER	11CT4E or 15CT4C	18CT4C 23CT4C	QUANTITY	TYPE	11CT4E or 15CT4C	18CT4C 23CT4C	
15CX4D			1	11CDX4B	1	2	11
15CX4D	2	4	1	11CDX4B		1	11
15CX4D	—	—	1	15CDX4D	—	1	11
18CX4D			1	11CDX4B	1	3	10
18CX4D	7	14	1	11CDX4B	1	2	11
18CX4D	13	26	1	11CDX4B		1	11
18CX4D			2	11CDX4B	1	2	11
18CX4D	10	20	2	11CDX4B		1	11
18CX4D			3	11CDX4B	—	1	10
18CX4D	5	10	3	11CDX4B	—	1	11
18CX4D	—	—	4	11CDX4B	—	1	11
18CX4D			1	15CDX4D	2	4	10
18CX4D	6	12	1	15CDX4D	1	2	10
18CX4D	10	20	1	15CDX4D		1	10
18CX4D	—	—	2	15CDX4D	—	1	10
18CX4D			1	18CDX4C	4	8	10
18CX4D	3	6	1	18CDX4C	3	6	10
18CX4D	6	12	1	18CDX4C	2	4	10
18CX4D	8	16	1	18CDX4C	1	2	10
18CX4D	10	20	1	18CDX4C		1	10
18CX4D			2	18CDX4C	1	2	10
18CX4D	1	2	2	18CDX4C		1	10
23CX4D			1	11CDX4B	1	3	10
23CX4D	15	30	1	11CDX4B	1	2	10
23CX4D	30	30	1	11CDX4B		1	10
23CX4D			2	11CDX4B	1	3	10
23CX4D	9	18	2	11CDX4B	1	2	10
23CX4D	20	40	2	11CDX4B		1	10

TABLE XIV. Limiting loads for MIL-S-20708 synchros in 400-hertz Control System C (Figure 60) - Continued.

	LOAD 1 LIMITING NUMBER OF CT UNITS		LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF CT's PER CDX (n_{ct}/n_{cdx})		DROP IN VOLTAGE GRADIENT FOR CT's IN LOAD 2 (%)
TRANSMITTER	11CT4E or 15CT4C	18CT4C 23CT4C	QUANTITY	TYPE	11CT4E or 15CT4C	18CT4C 23CT4C	
23CX4D			3	11CDX4B	1	2	10
23CX4D	15	30	3	11CDX4B		1	10
23CX4D			4	11CDX4B	1	2	10
23CX4D	11	22	4	11CDX4B		1	10
23CX4D			5	11CDX4B	1	2	11
23CX4D	7	14	5	11CDX4B	—	1	10
23CX4D			6	11CDX4B	—	1	9
23CX4D	3	6	6	11CDX4B	—	1	10
23CX4D	—	—	7	11CDX4B	—	1	10
23CX4D			1	15CDX4D	3	6	10
23CX4D	10	20	1	15CDX4D	2	4	10
23CX4D	20	40	1	15CDX4D	1	2	10
23CX4D	25	50	1	15CDX4D		1	10
23CX4D			2	15CDX4D	2	4	10
23CX4D	14	28	2	15CDX4D	1	2	10
23CX4D	20	40	2	15CDX4D		1	10
23CX4D			3	15CDX4D	1	3	10
23CX4D	5	10	3	15CDX4D	1	2	10
23CX4D	10	20	3	15CDX4D		1	10
23CX4D			4	15CDX4D	—	1	9
23CX4D	4	8	4	15CDX4D	—	1	10
23CX4D	—	—	5	15CDX4D	—	1	10
23CX4D			1	18CDX4C	7	14	10
23CX4D	8	16	1	18CDX4C	5	10	10
23CX4D	16	32	1	18CDX4C	3	6	10
23CX4D	24	48	1	18CDX4C	1	2	10
23CX4D	30	60	1	18CDX4C		1	10

TABLE XIV. Limiting loads for MIL-S-20708 synchros in 400-hertz Control System (Figure 60) - Continued.

	LOAD 1 LIMITING NUMBER OF CT UNITS		LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF CT's PER CDX (n_{ct}/n_{cdx})		DROP IN VOLTAGE GRADIENT FOR CT's IN LOAD 2 (%)
TRANSMITTER	11CT4E or 15CT4C	18CT4C 23CT4C	QUANTITY	TYPE	11CT4E or 15CT4C	18CT4C 23CT4C	
23CX4D			2	18CDX4C	4	8	10
23CX4D	10	20	2	18CDX4C	2	4	10
23CX4D	15	30	2	18CDX4C	1	2	10
23CX4D	20	40	2	18CDX4C		1	10
23CX4D			3	18CDX4C	2	4	10
23CX4D	6	12	3	18CDX4C	1	2	10
23CX4D	10	20	3	18CDX4C		1	10
23CX4D			4	18CDX4C	1	2	10
23CX4D	2	4	4	18CDX4C		1	10
23CX4D			1	23CDX4C	9	18	10
23CX4D	7	14	1	23CDX4C	6	12	10
23CX4D	14	28	1	23CDX4C	3	6	10
23CX4D	18	36	1	23CDX4C	1	2	10
23CX4D	20	40	1	23CDX4C		1	10
23CX4D			2	23CDX4C	2	4	10
23CX4D	3	6	2	23CDX4C	1	2	10
23CX4D	5	10	2	23CDX4C		1	10
78V-18CDX4C			1	11CDX4B	1	2	10
78V-18CDX4C	4	8	1	11CDX4B		1	10
78V-18CDX4C	—	—	2	11CDX4B	—	1	10
78V-18CDX4C			1	15CDX4D	1	2	10
78V-18CDX4C	2	4	1	15CDX4D		1	10
78V-18CDX4C			1	18CDX4C	1	3	10
78V-18CDX4C	1	2	1	18CDX4C	1	2	10
78V-18CDX4C	2	4	1	18CDX4C		1	10
78V-23CDX4C			1	11CDX4B	1	3	10
78V-23CDX4C	6	12	1	11CDX4B	1	2	10
78V-23CDX4C	14	28	1	11CDX4B		1	10

TABLE XIV. Limiting loads for MIL-S-20708 synchros in 400-hertz Control System C (Figure 60) - Continued.

	LOAD 1 LIMITING NUMBER OF CT UNITS		LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF CT's PER CDX (n_{ct}/n_{cdx})		DROP IN VOLTAGE GRADIENT FOR CT's IN LOAD 2 (%)
TRANSMITTER	11CT4E or 15CT4C	18CT4C 23CT4C	QUANTITY	TYPE	11CT4E or 15CT4C	18CT4C 23CT4C	
78V-23CDX4C			2	11CDX4B	1	2	10
78V-23CDX4C	10	20	2	11CDX4B		1	10
78V-23CDX4C			3	11CDX4B	1	2	11
78V-23CDX4C	5	10	3	11CDX4B		1	10
78V-23CDX4C	—	—	4	11CDX4B	—	1	10
78V-23CDX4C	—	—	5	11CDX4B	—	1	10
78V-23CDX4C			1	15CDX4D	2	5	10
78V-23CDX4C	2	4	1	15CDX4D	2	4	10
78V-23CDX4C	10	20	1	15CDX4D	1	2	10
78V-23CDX4C	14	28	1	15CDX4D		1	10
78V-23CDX4C			2	15CDX4D	1	2	10
78V-23CDX4C	7	14	2	15CDX4D		1	10
78V-23CDX4C	—	—	3	15CDX4D	—	1	10
78V-23CDX4C			1	18CDX4C	5	10	10
78V-23CDX4C	7	14	1	18CDX4C	3	6	10
78V-23CDX4C	13	26	1	18CDX4C	1	2	10
78V-23CDX4C	15	30	1	18CDX4C		1	10
78V-23CDX4C			2	18CDX4C	2	4	10
78V-23CDX4C	5	10	2	18CDX4C	1	2	10
78V-23CDX4C	8	16	2	18CDX4C		1	10
78V-23CDX4C	—	—	3	18CDX4C	—	1	10
78V-23CDX4C			1	23CDX4C	5	10	10
78V-23CDX4C	3	6	1	23CDX4C	3	6	10
78V-23CDX4C	7	14	1	23CDX4C	1	2	10
78V-23CDX4C	8	16	1	23CDX4C		1	10

TABLE XV. Limiting loads for MIL-S-20708 synchros in 60-hertz Torque System A.

TRANSMITTER	LIMITING NUMBER OF TR (OR TRX) UNITS			
	18TRX6B or	23TRX6B or	31TRX6A or	37TRX6A
18TRX6B	2	—	—	—
23TRX6B	5	2	—	—
31TRX6A	15	6	2	—
37TRX6A	35	13	5	2
78V-23TDX6C	1	—	—	—
78V-31TDX6C	11	4	1	—

TABLE XVI. Limiting loads for MIL-S-20708 synchros in 60-hertz Torque System B.

TRANSMITTER	DIFFERENTIALS		LIMITING NUMBER OF TR's OR TRX's PER TDX (n_b/n_d)			
	QUANTITY (n_d)	TYPE	18TRX6B	23TRX6B	31TRX6A	37TRX6A
31TRX6A	1 to 3	23TDX6C	1	—	—	—
37TRX6A	1 to 8	23TDX6C	1	—	—	—
37TRX6A	1	31TDX6C	9	3	1	—
37TRX6A	2	31TDX6C	7	2	—	—
78V-31TDX6C	1 or 2	23TDX6C	1	—	—	—

TABLE XVII. Limiting loads for MIL-S-20708 synchros in 60-hertz Torque System C.

	LOAD 1 LIMITING NUMBER OF TR's (OR TRX's)				LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF TR's (OR TRX's) PER TDX			
TRANS-MITTER	18TRX6B or	23TRX6B or	31TRX6A or	37TRX6A	QUANTITY	TYPE	18TRX6B or	23TRX6B or	31TRX6A or	37TRX6A
31TRX6A	—	—	—	—	1 to 3	23TDX6C	1	—	—	—
37TRX6A		—	—	—	1 to 8	23TDX6C	1	—	—	—
37TRX6A	1	—	—	—	1 to 3	23TDX6C	1	—	—	—
37TRX6A	—	—	—	—	1	31TDX6C	9			—
37TRX6A	1	—	—	—	1	31TDX6C	8			—
37TRX6A	5	2	—	—	1	31TDX6C	6		—	—
37TRX6A	11	4	1	—	1	31TDX6C	4		—	—
37TRX6A	20	7	2	1	1	31TDX6C	2	—	—	—
37TRX6A	25	9	3	1	1	31TDX6C	1	—	—	—
37TRX6A	—	—	—	—	1	31TDX6C		3		—
37TRX6A	5	2	—	—	1	31TDX6C		2	—	—
37TRX6A	15	6	2	—	1	31TDX6C		1	—	—
37TRX6A				—	1	31TDX6C			1	—
37TRX6A	—	—	—	—	2	31TDX6C	7		—	—
37TRX6A	2	—	—	—	2	31TDX6C	6		—	—
37TRX6A	5	2	—	—	2	31TDX6C	5		—	—
37TRX6A	13	5	1	—	2	31TDX6C	3		—	—
37TRX6A	25	9	3	1	2	31TDX6C	1	—	—	—
37TRX6A			—	—	2	31TDX6C		2	—	—
37TRX6A	3	1	—	—	2	31TDX6C		2	—	—
37TRX6A	13	5	1		2	31TDX6C		1	—	—
78V-31TDX6C	—	—	—	—	1 or 2	23TDX6C	1	—	—	—

TABLE XVIII. Optimum values of synchro capacitors for MIL-S-20708, 60-hertz, synchro control transformers and differential units.

TYPE	DELTA CONNECTED CAPACITORS FOR POWER CORRECTION NOMINAL ±10% (MICROFARADS)			
	TOTAL CAP.	CAP. PER LEG	CAP. BETWEEN TERMINALS	REMARKS
15CT6D	1.02	0.34	.51	Matched to within 1 percent
23CT6D	1.02	0.34	.51	Matched to within 1 percent
18CDX6D	2.40	0.80	1.20	Matched to within 1 percent
23CDX6C	3.60	1.20	1.80	Matched to within 1 percent
23TDX6C	10.40	3.40	5.10	Matched to within 1 percent
31TDX6C	30.00	10.00	15.00	Matched to within 1 percent

TABLE XIX. Limiting CT loads, additional to torque loads of Tables XV, for MIL-S-20708 synchros in 60-hertz Mixed System A.

TX IN TORQUE SYSTEM A, TABLE XV	LIMITING NUMBER OF CT UNITS ADDITIONAL TO TORQUE LOADS OF TABLE XV
	15CT6D or 23CT6D
18TRX6B	2
23TRX6B	3
31TRX6A	10
37TRX6A	25
78V-23TDX6C	2
78V-31TDX6C	10

TABLE XX. Limiting CT loads, additional to torque loads of Tables XVI and XVII, for MIL-S-20708 synchros in 60-hertz Mixed System B.

TR OR TRX IN TORQUE SYSTEMS B AND C, TABLES XVI AND XVII	LIMITING NUMBER OF CT's PER TR (n_{ct}) ADDITIONAL TO TORQUE LOADS OF TABLES XVI AND XVII
	15CT6D or 23CT6D
For n 18TRX6B, n_{ct} =	1 or 6 n (larger of the two)
For n 23TRX6B, n_{ct} =	2 or 1.8 n (larger of the two)
For n 31TRX6A, n_{ct} =	5n
For n 37TRX6A, n_{ct} =	10n

TABLE XXI. Limiting CDX-CT loads that replace a TDX-TR branch of Tables XVI and XVII for MIL-S-20708 synchros in 60-hertz Mixed System C.

TDX-TR BRANCH IN TORQUE SYSTEMS B AND C, TABLES XVI AND XVII	NUMBER AND TYPE OF CDX UNITS REPLACING ONE TDX-TR BRANCH		CT UNITS PER CDX
	NUMBER	TYPE	15CT6D or 23CT6D
23TDX6C with its TR load	1	23CDX6C	1
31TDX6C with its TR load	1 to 5	23CDX6C	1

TABLE XXII. Limiting loads for MIL-S-20708 synchros in 60-hertz Control System A.

TRANSMITTER	LIMITING NUMBER OF CT's 15CT6D or 23CT6D	DROP IN VOLTAGE GRADIENT OF CT (%)
18TRX6B	3	18
23CX6D	3	18
23TRX6B	4	15
31TRX6A	18	15
37TRX6A	45	13
78V-23CDX6C	2	20
78V-23TDX6C	3	15
78V-31TDX6C	20	15

TABLE XXIII. Limiting loads for MIL-S-20708 synchros in 60-hertz Control System B.

TRANSMITTER	DIFFERENTIAL		LIMITING NUMBER OF CT's PER CDX	DROP IN VOLTAGE GRADIENT OF CT (%)
	QUANTITY	TYPE	15CT6D or 23CT6D	
23TRX6B	1	23CDX6C	1	20
31TRX6A	1	23CDX6C	1	16
31TRX6A	2	23CDX6C	1	17
31TRX6A	1	23TDX6C	2	16
31TRX6A	2	23TDX6C	1	16
37TRX6A	1	23CDX6C	1	15
37TRX6A	1	23TDX6C	3	16
37TRX6A	2	23TDX6C	2	15
37TRX6A	3	23TDX6C	2	15
37TRX6A	4	23TDX6C	1	14
37TRX6A	5	23TDX6C	1	14
37TRX6A	6	23TDX6C	1	15
37TRX6A	7	23TDX6C	1	15
37TRX6A	1	31TDX6C	10	15
37TRX6A	2	31TDX6C	4	15
78V-31TDX6C	1	23CDX6C	1	16
78V-31TDX6C	2	23CDX6C	1	17
78V-31TDX6C	3	23CDX6C	1	18
78V-31TDX6C	1	23CDX6C	3	18
78V-31TDX6C	2	23TDX6C	2	18
78V-31TDX6C	3	23TDX6C	1	18
78V-31TDX6C	1	31TDX6C	2	18

TABLE XXIV. Limiting loads for MIL-S-20708 synchros in 60-hertz Control System C.

	LOAD 1 LIMITING NUMBER OF CT UNITS	LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF CT's PER CDX	DROP IN VOLTAGE GRADIENT FOR CT's IN LOAD 2 (%)
TRANSMITTER	15CT6D or 23CT6D	QUANTITY	TYPE	15CT6D or 23CT6D	
23TRX6B	—	1	23CDX6C	1	20
31TRX6A		1	23CDX6C	1	16
31TRX6A	3	1	23CDX6C	1	17
31TRX6A	—	2	23CDX6C	1	17
31TRX6A		1	23TDX6C	2	16
31TRX6A	7	1	23TDX6C	1	16
31TRX6A	—	2	23TDX6C	1	16
37TRX6A		1	23CDX6C	1	15
37TRX6A	10	1	23CDX6C	1	16
37TRX6A		1	23TDX6C	3	16
37TRX6A	10	1	23TDX6C	2	15
37TRX6A	35	1	23TDX6C	1	15
37TRX6A		2	23TDX6C	2	15
37TRX6A	30	2	23TDX6C	1	15
37TRX6A		3	23TDX6C	2	15
37TRX6A	25	3	23TDX6C	1	15
37TRX6A		4	23TDX6C	1	14
37TRX6A	15	4	23TDX6C	1	15
37TRX6A		5	23TDX6C	1	14
37TRX6A	9	5	23TDX6C	1	15
37TRX6A		6	23TDX6C	1	15
37TRX6A	3	6	23TDX6C	1	15
37TRX6A	—	7	23TDX6C	1	15

TABLE XXIV.. Limiting loads for MIL-S-20708 synchros in 60-hertz Control System C - Continued.

	LOAD 1 LIMITING NUMBER OF CT UNITS	LOAD OF DIFFERENTIALS		LOAD 2 LIMITING NUMBER OF CT's PER CDX	DROP IN VOLTAGE GRADIENT FOR CT's IN LOAD 2 (%)
TRANSMITTER	15CT6D or 23CT6D	QUANTITY	TYPE	15CT6D or 23CT6D	
37TRX6A		1	31TDX6C	10	15
37TRX6A	12	1	31TDX6C	8	15
37TRX6A	25	1	31TDX6C	5	15
37TRX6A	35	1	31TDX6C	3	15
37TRX6A	45	1	31TDX6C	1	15
37TRX6A		2	31TDX6C	4	15
37TRX6A	6	2	31TDX6C	3	15
37TRX6A	12	2	31TDX6C	2	15
37TRX6A	18	2	31TDX6C	1	15
78V-31TDX6C		1	23CDX6C	1	16
78V-31TDX6C	7	1	23CDX6C	1	18
78V-31TDX6C		2	23CDX6C	1	17
78V-31TDX6C	3	2	23CDX6C	1	18
78V-31TDX6C	[redacted]	3	23CDX6C	1	18
78V-31TDX6C		1	23TDX6C	3	18
78V-31TDX6C	8	1	23TDX6C	2	18
78V-31TDX6C	15	1	23TDX6C	1	18
78V-31TDX6C		2	23TDX6C	2	18
78V-31TDX6C	9	2	23TDX6C	1	18
78V-31TDX6C		3	23TDX6C	1	18
78V-31TDX6C	2	3	23TDX6C	1	18
78V-31TDX6C		1	31TDX6C	2	18
78V-31TDX6C	3	1	31TDX6C	1	18

TABLE XXV. Size of pre-standard type synchros.

SIZE	APPROXIMATE DIAMETER (inches)	APPROXIMATE WEIGHT (pounds)	APPROXIMATE EQUIVALENT DIAMETER OF STANDARD SYNCHRO (SIZE)
1	2.25	2	23
3	3.1	3	31
5	3.37 to 3.62	5	37
6	4.5	8	--
7	5.75	18	--

TABLE XXVI. Function of pre-standard type synchros.

LETTER	FUNCTION
G	Transmitter
D	Differential Receiver
DG	Differential Transmitter
CT	Control Transformer
H	High-Speed Unit
B	Bearing-Mounted Unit
N	Nozzle-Mounted Unit
S	Special Unit
F*	Flange-Mounted Receiver

*This letter is normally omitted if letters other than H or S occur in the type designation.

TABLE XXVII. MIL-S-20708 QPL synchros.

TYPE DESIGNATION & TOLERANCE	20708/79 26V-08CT4C	20708/7 26V-11CT4D	20708/1 11CT4E
Primary voltage (V), ± 1%	10.2	10.2	78
Primary current (mA), maximum	23.0	86.0	18.0
Primary power (watts), maximum	0.053	0.18	0.24
Impedance (ohms), min-max			
Zro			
Zss			
Zso	444-570	118-150	4350-5700
Zrs	830-940	130-170	585-700
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	76.0-81.0	78.0-84.0	77.3-83.5
Zrs	16.0-20.0	23.0-35.0	22.0-32.0
Transformation ratio, ± 2%	2.203	2.203	0.735
Phase shift, lead (degrees), varies	8.0 ±1.5	4.5 ±1.5	5.0 ±1.0
Electrical error (minutes), max	7.0	7.0	7.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	30.0	18.0	60.0
Fundamental	25.0	15.0	32.0
Friction torque (oz-in), max	0.04	0.07	0.07
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	10.0	10.0	10.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0004	0.0006	0.0006
End Play (inches), varies	0.0007 max	0.0010 ±0.0005	0.0010 ±0.0005

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/15 15CT4C	20708/21 15CT6D	20708/29 18CT4C
Primary voltage (V), ± 1%	78	26	78
Primary current (mA), maximum	10.0	13.0	7.0
Primary power (watts), maximum	0.17	0.25	0.06
Impedance (ohms), min-max			
Zro			
Zss			
Zso	7800-9512	6000-7500	12000-14800
Zrs	1050-1300	1300-1650	980-1190
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	77.8-84.5	78.0-82.0	82.0-84.5
Zrs	26.0-33.0	13.0-18.0	42.0-52.0
Transformation ratio, ± 2%	0.735	0.735	0.735
Phase shift, lead (degrees), varies	5.5 ±1.5	9.0 ±2.0	2.0 ±2.0
Electrical error (minutes), max	6.0	6.0	6.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	60.0	65.0	30.0
Fundamental	32.0	45.0	20.0
Friction torque (oz-in), max	0.05	0.05	0.10
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	10.0	10.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (-5%), (watts), max	----	----	----
Radial Play (inches), max	0.0006	0.0006	0.0006
End Play (inches), varies	0.0010 ±0.0005	0.0010 ±0.0005	0.0015 ±0.0010

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/34 18CT6D	20708/46 23CT4C	20708/53 23CT6D
Primary voltage (V), ± 1%	78	78	78
Primary current (mA), maximum	17.0	5.7	18.5
Primary power (watts), maximum	0.43	0.06	0.48
Impedance (ohms), min-max			
Zro			
Zss			
Zso	4600-5800	13400-16700	4200-5100
Zrs	1600-2050	1040-1260	1350-1650
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	70.0-76.0	81.0-84.5	70.0-76.0
Zrs	14.5-18.0	46.0-56.0	14.0-20.0
Transformation ratio, ± 2%	0.735	0.735	0.735
Phase shift, lead (degrees), varies	16.0 ±3.0	2.3 ±2.0	14.0 ±2.5
Electrical error (minutes), max	6.0	6.0	6.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	45.0	45.0	45.0
Fundamental	25.0	20.0	30.0
Friction torque (oz-in), max	0.10	0.20	0.20
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	10.0	20.0	10.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0006	0.0010	0.0010
End Play (inches), varies	0.0015 ±0.0010	0.0025 ±0.0020	0.0025 ±0.0020

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/78 26V-08CX4C	20708/8 26V-11CX4C	20708/2 11CX4E
Primary voltage (V), ± 1%	26	26	115
Primary current (mA), maximum	153.0	130.0	31.0
Primary power (watts), maximum	0.84	0.41	0.59
Impedance (ohms), min-max			
Zro	170-215	200-300	3720-4700
Zss	11.0-15.0	6.0-12.0	410-500
Zso			
Zrs			
Impedance angle (degrees), min-max			
Zro	77.5-80.5	80.5-84.0	80.0-84.0
Zss	9.0-15.0	18.0-30.0	17.0-26.0
Zso			
Zrs			
Transformation ratio, ± 2%	0.454	0.454	0.783
Phase shift, lead (degrees), varies	8.5 ±1.5	4.0 ±1.5	4.5 ±1.5
Electrical error (minutes), max	7.0	7.0	7.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	30.0	19.0	75.0
Fundamental	20.0	12.0	45.0
Friction torque (oz-in), max	0.04	0.07	0.07
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	20.0	20.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (-5%), (watts), max	----	----	----
Radial Play (inches), max	0.0004	0.0006	0.0006
End Play (inches), varies	0.0007 max	0.0010 ±0.0005	0.0010 ±0.0005

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/14 15CX4D	20708/28 18CX4D	20708/33 18CX6C
Primary voltage (V), ± 1%	115	115	115
Primary current (mA), maximum	85.0	110.0	40.0
Primary power (watts), maximum	1.2	1.1	1.1
Impedance (ohms), min-max			
Zro	1402-1643	1045-1400	2875-3375
Zss	123-138	40.0-57.0	660-810
Zso			
Zrs			
Impedance angle (degrees), min-max			
Zro	81.4-84.6	84.0-87.5	76.0-80.0
Zss	26.5-31.5	34.0-48.0	9.0-13.0
Zso			
Zrs			
Transformation ratio, ± 2%	0.783	0.783	0.783
Phase shift, lead (degrees), varies	4.0 ±1.5	1.5 ±1.5	11.0 ±1.5
Electrical error (minutes), max	6.0	6.0	8.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	60.0	60.0	85.0
Fundamental	32.0	40.0	30.0
Friction torque (oz-in), max	0.05	0.10	0.10
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	20.0	20.0	25.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0006	0.0006	0.0006
End Play (inches), varies	0.0010 ±0.0005	0.0015 ±0.0010	0.0015 ±0.0010

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/45 23CX4D	20708/52 23CX6D	20708/80 26V-08CDX4C
Primary voltage (V), ± 1%	115	115	10.2
Primary current (mA), maximum	245.0	80.0	108.0
Primary power (watts), maximum	2.1	1.7	0.29
Impedance (ohms), min-max			
Zro	470-580	1450-1700	
Zss	21.6-26.0	155-310	
Zso			95.0-120.0
Zrs			35.0-48.0
Impedance angle (degrees), min-max			
Zro	84.0-87.5	79.0-83.0	
Zss	42.0-47.0	10.0-15.0	
Zso			74.0-79.0
Zrs			15.0-20.0
Transformation ratio, ± 2%	0.783	0.783	1.154
Phase shift, lead (degrees), varies	1.0 ±1.0	6.5 ±1.5	9.5 ±1.5
Electrical error (minutes), max	6.0	6.0	7.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	48.0	60.0	30.0
Fundamental	32.0	30.0	20.0
Friction torque (oz-in), max	0.20	0.20	0.04
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	20.0	20.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (-5%), (watts), max	----	----	----
Radial Play (inches), max	0.0010	0.0010	0.0004
End Play (inches), varies	0.0025 ±0.0020	0.0025 ±0.0020	0.0007 max

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/9 26V-11CDX4C	20708/81 11CDX4B	20708/16 15CDX4D
Primary voltage (V), ± 1%	10.2	78	78
Primary current (mA), maximum	150.0	49.0	90.0
Primary power (watts), maximum	0.30	0.64	1.1
Impedance (ohms), min-max			
Zro			
Zss			
Zso	68.0-85.0	1590-2050	870-1150
Zrs	20.0-26.0	470-570	195-290
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	77.0-82.0	79.0-85.0	79.0-85.0
Zrs	22.0-30.0	23.0-33.0	27.0-37.0
Transformation ratio, ± 2%	1.154	1.154	1.154
Phase shift, lead (degrees), varies	6.0 ±2.0	4.0 ±2.0	5.5 ±2.0
Electrical error (minutes), max	7.0	7.0	6.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	26.0	90.0	60.0
Fundamental	17.0	60.0	32.0
Friction torque (oz-in), max	0.07	0.07	0.07
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	10.0	20.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0006	0.0006	0.0006
End Play (inches), varies	0.0010 ±0.0005	0.0010 ±0.0005	0.0010 ±0.0005

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/30 18CDX4C	20708/36 18CDX6D	20708/47 23CDX4C
Primary voltage (V), ± 1%	78	78	78
Primary current (mA), maximum	128.0	52.0	285.0
Primary power (watts), maximum	1.1	1.3	2.6
Impedance (ohms), min-max			
Zro			
Zss			
Zso	610-785	1500-1875	275-340
Zrs	76-110	915-1225	37.0-50.0
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	83.0-86.5	69.0-75.0	82.5-85.5
Zrs	40.0-55.0	12.0-18.0	45.0-50.0
Transformation ratio, ± 2%	1.154	1.154	1.154
Phase shift, lead (degrees), varies	2.0 ±2.0	15.5 ±2.0	2.0 ±1.5
Electrical error (minutes), max	6.0	7.0	7.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	75.0	100.0	60.0
Fundamental	40.0	60.0	30.0
Friction torque (oz-in), max	0.10	0.10	0.20
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	20.0	20.0	30.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0006	0.0006	0.0010
End Play (inches), varies	0.0015 ±0.0010	0.0015 ±0.0010	0.0025 ±0.0020

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/54 23CDX6C	20708/6 26V-11TX4C	20708/32 18TRX4A
Primary voltage (V), ± 1%	78	26	115
Primary current (mA), maximum	90.0	280.0	400.0
Primary power (watts), maximum	1.7	1.0	4.0
Impedance (ohms), min-max			
Zro		----	----
Zss		3.3-4.2	16.0-21.0
Zso	867-1100		
Zrs	448-550		
Impedance angle (degrees), min-max			
Zro		----	----
Zss		17.0-24.0	38.0-45.0
Zso	75.0-79.0		
Zrs	14.5-23.0		
Transformation ratio, ± 2%	1.154	0.454	0.783
Phase shift, lead (degrees), varies	11.0 ±2.5	4.0 ±1.0	4.0 max
Electrical error (minutes), max	8.0	7.0	8.0
Receiver error (minutes), max	----	----	45.0
Null voltage (mV), max			
Total	65.0	----	100.0
Fundamental	40.0	----	50.0
Friction torque (oz-in), max	0.20	0.07	----
Torque gradient (oz-in), min	----	0.0080	0.10
Temperature rise (degrees C), max	20.0	20.0	35.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	1.0
177° ± 2°	----	----	2.0
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	1.4	5.6
Radial Play (inches), max	0.0010	0.0006	0.0006
End Play (inches), varies	0.0025 ±0.0020	0.0010 ±0.0005	0.0020 ±0.0015

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/35 18TRX6B	20708/50 23TRX4A	20708/56 23TRX6B
Primary voltage (V), ± 1%	115	115	115
Primary current (mA), maximum	100.0	720.0	210.0
Primary power (watts), maximum	4.0	4.6	5.6
Impedance (ohms), min-max			
Zro	----	----	----
Zss	350-430	6.5-8.1	110-145
Zso			
Zrs			
Impedance angle (degrees), min-max			
Zro	----	----	----
Zss	10.0-15.0	44.0-55.0	10.0-17.0
Zso			
Zrs			
Transformation ratio, ± 2%	0.783	0.783	0.783
Phase shift, lead (degrees), varies	16.0 max	2.0 max	11.0 max
Electrical error (minutes), max	6.0	6.0	45.0
Receiver error (minutes), max	45.0	45.0	8.0
Null voltage (mV), max			
Total	300.0	150.0	160.0
Fundamental	50.0	30.0	60.0
Friction torque (oz-in), max	----	----	----
Torque gradient (oz-in), min	0.050	0.25	0.12
Temperature rise (degrees C), max	40.0	30.0	35.0
Synchronizing time (seconds), max			
30° ± 2°	1.0	1.0	1.0
177° ± 2°	2.0	2.0	2.0
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	5.6	6.5	8.1
Radial Play (inches), max	0.0006	0.0010	0.0010
End Play (inches), varies	0.0020 ±0.0015	0.0025 ±0.0020	0.0025 ±0.0020

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/62 31TRX4A	20708/66 31TRX6A	20708/74 37TRX6A
Primary voltage (V), ± 1%	115	115	115
Primary current (mA), maximum	1650.0	440.0	830.0
Primary power (watts), maximum	14.4	6.6	9.25
Impedance (ohms), min-max			
Zro	----	----	----
Zss	2.5-5.5	24.0-33.0	7.0-10.0
Zso			
Zrs			
Impedance angle (degrees), min-max			
Zro	----	----	----
Zss	60.0-75.0	16.0-24.0	30.0-40.0
Zso			
Zrs			
Transformation ratio, ± 2%	0.783	0.783	0.783
Phase shift, lead (degrees), varies	2.0 max	6.5 max	3.5 max
Electrical error (minutes), max	8.0	10.0	10.0
Receiver error (minutes), max	36.0	36.0	36.0
Null voltage (mV), max			
Total	170.0	170.0	170.0
Fundamental	35.0	35.0	35.0
Friction torque (oz-in), max	----	----	----
Torque gradient (oz-in), min	0.67	0.40	0.90
Temperature rise (degrees C), max	60.0	35.0	35.0
Synchronizing time (seconds), max			
30° ± 2°	1.0	1.0	1.0
177° ± 2°	2.0	2.0	2.0
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	27.0	9.4	18.0
Radial Play (inches), max	0.0008	0.0008	0.0008
End Play (inches), varies	0.0030 ±0.0020	0.0030 ±0.0020	0.0030 ±0.0020

TABLE XXVII. MIL-S-20708 QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/48 23TDX4C	20708/55 23TDX6C	20708/68 31TDX6C
Primary voltage (V), ± 1%	78	78	90 nom
Primary current (mA), maximum	866.0	215.0	725.0
Primary power (watts), maximum	7.0	4.8	7.7
Impedance (ohms), min-max			
Zro			
Zss			
Zso	90-112	370-460	----
Zrs	11.0-15.0	175-220	44.0 max
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	84.0-88.0	74.0-78.0	----
Zrs	47.0-53.0	15.0-20.0	27.0 min
Transformation ratio, ± 2%	1.154	1.154	1.154
Phase shift, lead (degrees), varies	2.0 ±1.0	11.5 ±2.0	6.5 max
Electrical error (minutes), max	8.0	6.0	10.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	----	----	----
Fundamental	----	----	----
Friction torque (oz-in), max	0.20	0.20	0.50
Torque gradient (oz-in), min	0.16	0.03	0.30
Temperature rise (degrees C), max	25.0	25.0	18.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	7.84	6.72	----
Radial Play (inches), max	0.0010	0.0010	0.0008
End Play (inches), varies	0.0025 ±0.0020	0.0025 ±0.0020	0.0030 ±0.0020
DC resistance (ohms), reference			
Rotor	----	----	24
Stator	----	----	19

TABLE XXVIII. MIL-S-20708 non-QPL synchros.

TYPE DESIGNATION	20708/136 26V-05CT4A	20708/142 26V-23CT4A	20708/504 15CT6B
Primary voltage (V), ±1%	11.8	20.4 ±1.2	90 nom
Primary current (mA), maximum	20.0	1.2 nom	20-25 min-max
Primary power (watts), maximum	0.045 nom	0.002 nom	0.7
Impedance (ohms), varies	R±20%+jx±20%	R±15%+jx±10%	
Zro		735+j7475	
Zss			
Zso	175+j615	1400+j17500	3611 nom
Zrs	855+j240	660+j460	1423 nom
Impedance angle (degrees), varies			
Zro	----	----	
Zss	----		
Zso		----	70.1 nom
Zrs		----	15.9 nom
Transformation ratio, varies	1.765 ±3%	0.635 ±0.02	0.735 ±2%
Phase shift, lead (degrees), varies	16.0 max	2.0 ±0.5	20.0 ±2.0
Electrical error (minutes), max	10.0	20.0	6.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	60.0	7.0	90.0
Fundamental	40.0	5.0	60.0
Friction torque (oz-in), max	0.04	0.2	0.05
@ -55°C	----	0.4	----
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	10.0	20.0	10.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0008	0.0010	0.0004
End Play (inches), varies	0.0001 min 0.0010 max	0.0020 max	0.0015 max
DC resistance, (ohms), ± 15%			
Rotor	400	----	----
Stator	620	----	----

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION	20708/25 16CTB4B	20708/39 19CTB4B	20708/42 19CTB6B
Primary voltage (V), ± 1%	78	78	78
Primary current (mA), maximum	24.0	7.0	20.0
Primary power (watts), maximum	0.35	0.25	0.35
Impedance (ohms), min-max			
Zro			
Zss			
Zso	----	----	----
Zrs	----	----	----
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	----	----	----
Zrs	----	----	----
Transformation ratio, ± 2%	0.735	0.735	0.735
Phase shift, lead (degrees), varies	8.0 max	3.0 max	20.0 max
Electrical error (minutes), max	10.0	8.0	6.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	60.0	65.0	60.0
Fundamental	40.0	35.0	30.0
Friction torque (oz-in), max	0.05	0.10	0.15
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	----	----	----
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0006	0.0006	0.0006
End Play (inches), varies	0.0015 max	0.0030 max	0.0030 max
DC resistance (ohms), reference			
Rotor	----	----	----
Stator	----	----	----

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION	20708/135 26V-05CX4A	20708/131 15CX4F	20708/20 15CX6C
Primary voltage (V), ± 1%	26	115	115
Primary current (mA), maximum	60.0	100.0	22.0
Primary power (watts), maximum	0.35 nom	1.40	0.43
Impedance (ohms), min-max	R±20%+jx±20%		
Zro	150+j520	1800	5335-6265
Zss	56+j8.6	1.5	675-825
Zso			
Zrs			
Impedance angle (degrees), varies			
Zro	----	84.5	80.0-83.0
Zss	----	25.0	11.0-16.0
Zso			
Zrs			
Transformation ratio, varies	0.454 ±3%	0.1026 ±2%	0.783 ±2%
Phase shift, lead (degrees), varies	16.0 max	2.5 ±1.5	7.0 ±1.5
Electrical error (minutes), max	10.0	6.0	6.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	40.0	25.0	90.0
Fundamental	30.0	12.0	45.0
Friction torque (oz-in), max	0.04	0.05	0.05
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	10.0	20.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0008	0.0006	0.0006
End Play (inches), varies	0.0001 min 0.0010 max	0.0010 ±0.0005	0.0010 ±0.0005
DC resistance (ohms), reference			
Rotor	----	----	----
Stator	----	----	----

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION	20708/137 26V-05CDX4A	20708/22 15CDX6C	20708/138 31CX4A
Primary voltage (V), ± 1%	11.8	78	115
Primary current (mA), maximum	44.0	38.0	950.0
Primary power (watts), maximum	0.115 nom	0.6	8.3 nom
Impedance (ohms), min-max	R±20%+jx±20%		
Zro			121-166
Zss			3.4-5.9
Zso	95+j290	2050-2600	
Zrs	175+j45	900-1200	
Impedance angle (degrees), min-max			
Zro			82-87
Zss			51-72
Zso	----	77.0-83.0	
Zrs	----	11.0-17.0	
Transformation ratio, varies	1.154 ±3%	1.154 ±3%	0.783 ±3%
Phase shift, lead (degrees), varies	18.0 max	9.0 ±2.0	1.5 max
Electrical error (minutes), max	10.0	7.0	8.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	40.0	100.0	100.0
Fundamental	30.0	60.0	35.0
Friction torque (oz-in), max	0.04	0.07	0.5
Torque gradient (oz-in), min	----	----	----
Temperature rise (degrees C), max	10.0	20.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	----	----	----
Radial Play (inches), max	0.0008	0.0006	0.0008
End Play (inches), varies	0.0001 min 0.0010 max	0.0010 ±0.0005	0.0030 ±0.0020
DC resistance (ohms), varies			
Rotor	53.6 max	37 ref	----
Stator	52 nom	12 ref	----

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION	20708/139 31CX6A	20708/144 26V-08TR4A	20708/500 26V-10TR4
Primary voltage (V), ± 1%	115	26	26
Primary current (mA), maximum	0.191	110.0	142.0
Primary power (watts), maximum	2.26 nom	0.54 nom	0.62 nom
Impedance (ohms), min-max		R±15%+jx±10%	
Zro	693 ±15%	52+j258	
Zss	63 nom	15+j3 ref	11 nom
Zso		12+j44	
Zrs			
Impedance angle (degrees), min-max			
Zro	83.2 ±2°	——	
Zss	20.0 nom	——	15 nom
Zso			
Zrs			
Transformation ratio, ± 2%	0.783	0.454	0.454
Phase shift, lead (degrees), varies	4.4 ±0.5	8.5 ±1.5	7.5 max
Electrical error (minutes), max	8.0	——	——
Receiver error (minutes), max	——	1.20	60.0
Null voltage (mV), max			
Total	100.0	——	——
Fundamental	30.0	——	——
Friction torque (oz-in) @ 25°C, max	0.5	0.005	——
@ -55°C and 125°C	——	0.010	——
Torque gradient (oz-in), min	——	0.002 min	0.003 min
Temperature rise (degrees C), max	10.0	20.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	——	2.0	2.0
177° ± 2°	——	3.0	4.0
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	——	——	1.4
Radial Play (inches), max	0.0008	0.0010	0.0010
End Play (inches), varies	0.0030 ±0.0020	0.0020 min 0.0050 max	0.0020 min 0.0050 max
DC resistance (ohms), reference			
Rotor	——	38.0	——
Stator	——	12.0	——

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION	20708/3 11TR4C	20708/145 26V-08TX4A	20708/4 11TX4C
Primary voltage (V), ± 1%	115	26	115
Primary current (mA), maximum	60.0	110.0	60.0
Primary power (watts), maximum	1.0	0.54 nom	1.0
Impedance (ohms), min-max		R±15%+jx±10%	
Zro		52+j258	
Zss	180-250	15+j3 ref	180-250
Zso		12+j44	
Zrs			
Impedance angle (degrees), min-max			
Zro		----	
Zss	22.0-28.0	----	22.0-28.0
Zso		----	
Zrs			
Transformation ratio, ± 2%	0.783	0.454	0.783
Phase shift, lead (degrees), varies	6.0 max	8.5 ±1.5	6.0 max
Electrical error (minutes), max	----	7.0	7.0
Receiver error (minutes), max	60.0	----	----
Null voltage (mV), max			
Total	----	30.0	----
Fundamental	----	20.0	----
Friction torque (oz-in) @ 25°C, max	----	0.04	0.07
@ -55°C and 125°C	----	0.12	----
Torque gradient (oz-in), min	0.0080	0.0020	0.0080
Temperature rise (degrees C), max	25.0	20.0	25.0
Synchronizing time (seconds), max			
30° ± 2°	1.0	----	----
177° ± 2°	2.0	----	----
Variation of voltage (± 10%) and Frequency (-5%), (watts), max	1.45	----	1.45
Radial Play (inches), max	0.0006	0.0004	0.0006
End Play (inches), varies	0.0025 ±0.0020	0.0003 min 0.0008 max	0.0010 ±0.0005
DC resistance (ohms), reference			
Rotor	----	36	----
Stator	----	24	----

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION	20708/49 23TDR4B	20708/67 31TDR6B	20708/143 26V-08TDX4A
Primary voltage (V), ± 1%	78	78	11.8
Primary current (mA), maximum	950.0	748.0	91.0
Primary power (watts), maximum	5.2	7.8	0.21 nom
Impedance (ohms), min-max			R±15%+jx±10%
Zro			35+j125
Zss	—		
Zso		—	28+j116
Zrs		—	47+j13 ref
Impedance angle (degrees), min-max			
Zro			—
Zss	—		
Zso		—	—
Zrs		—	—
Transformation ratio, ± 2%	1.154	1.154	1.154
Phase shift, lead (degrees), varies	4.0 max	6.5 max	9.0 ±1.5
Electrical error (minutes), max	6.0	10.0	7.0
Receiver error (minutes), max	45.0	48.0	—
Null voltage (mV), max			
Total	—	—	30.0
Fundamental	—	—	20.0
Friction torque (oz-in) @ 25°C, max	—	—	0.04
@ -55°C and 125°C	—	—	0.12
Torque gradient (oz-in), min	0.16	0.30	—
Temperature rise (degrees C), max	25.0	18.0	20.0
Synchronizing time (seconds), max			
30° ± 2°	1.0	1.0	—
177° ± 2°	2.0	2.0	—
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	—	—	—
Radial Play (inches), max	0.0010	0.0008	0.0004
End Play (inches), varies	0.0050 max	0.0030	0.0003 min
DC resistance (ohms), reference			
Rotor	—	—	—
Stator	—	—	—

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION	20708/17 15TDX4C	20708/31 18TDX4C	20708/76 37TDX6A
Primary voltage (V), ± 1%	78	78	78
Primary current (mA), maximum	215.0	450.0	2050.0
Primary power (watts), maximum	3.5	4.5	15.6
Impedance (ohms), min-max			
Zro			
Zss			
Zso	375-525	178-266	----
Zrs	113-138	26.0-38.0	----
Impedance angle (degrees), min-max			
Zro			
Zss			
Zso	80.0-84.0	83.0-87.0	----
Zrs	27.0-33.0	47.0-56.0	----
Transformation ratio, ± 2%	1.154	1.154	1.154
Phase shift, lead (degrees), varies	5.0 max	3.0 ±1.0	3.0 max
Electrical error (minutes), max	8.0	8.0	10.0
Receiver error (minutes), max	----	----	----
Null voltage (mV), max			
Total	----	----	----
Fundamental	----	----	----
Friction torque (oz-in), max	0.05	0.10	0.50
Torque gradient (oz-in), min	0.011	0.06	1.10
Temperature rise (degrees C), max	20.0	20.0	----
Synchronizing time (seconds), max			
30° ± 2°	----	----	----
177° ± 2°	----	----	----
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	4.9	7.0	----
Radial Play (inches), max	0.0006	0.0006	0.0008
End Play (inches), varies	0.0010 ±0.0005	0.0015 ±0.0010	0.0030 ±0.0020
DC resistance (ohms), reference			
Rotor	----	----	----
Stator	----	----	----

TABLE XXVIII. MIL-S-20708 non-QPL synchros - Continued.

TYPE DESIGNATION & TOLERANCE	20708/19 15TRX4A	20708/23 15TRX6A	20708/70 37TRX4A
Primary voltage (V), ± 1%	115	115	115
Primary current (mA), maximum	190.0	80.0	1885.0
Primary power (watts), maximum	2.9	2.8	20.0
Impedance (ohms), min-max			
Zro			
Zss	50.0-82.0	920 max	3.0-4.0
Zso			
Zrs			
Impedance angle (degrees), min-max			
Zro			
Zss	33.0-46.0	18.0 max	66.0-70.0
Zso			
Zrs			
Transformation ratio, ± 2%	0.783	0.783	0.783
Phase shift, lead (degrees), varies	5.0 max	20.0 max	1.0 max
Electrical error (minutes), max	6.0	8.0	8.0
Receiver error (minutes), max	45.0	45.0	36.0
Null voltage (mV), max			
Total	100.0	500.0	170.0
Fundamental	50.0	50.0	35.0
Friction torque (oz-in), max	----	----	----
Torque gradient (oz-in), min	0.030	0.030	0.9
Temperature rise (degrees C), max	35.0	35.0	60.0
Synchronizing time (seconds), max			
30° ± 2°	1.0	1.0	1.0
177° ± 2°	2.0	2.0	2.0
Variation of voltage (± 10%) and Frequency (±5%), (watts), max	4.1	5.5	32.5
Radial Play (inches), max	0.0006	0.0006	0.0008
End Play (inches), varies	0.0020 ±0.0010	0.0020 ±0.0010	0.0030 ±0.0020
DC resistance (ohms), reference			
Rotor	----	----	----
Stator	----	----	----

TABLE XXIX. Pre-standard synchros of MIL-S-2335.

TYPE DESIGNATION	1F 1HF	3F 3HF 3B	5F 5HF 5B	5N	5SB	5SN	2R 37TR- 37TR6A
Primary voltage (nominal)	115	115	115	115	115	115	115
Energizing Current (mA) (max)	300	400	600	600	1000	1000	400
Energizing Power (watts) (max)	4.8	5.5	7.0	7.0	10	10	6.5
Secondary Peak (min) Voltage limits (max)	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8
No Load Temp. Rise (°C) (max)	50	50	50	50	50	50	50
Electrical Error (minutes) (max) Static Accuracy	90 (1F) 150 (1HF)	36 (3F, 3B) 60 (3HF)	36 (3F, 5B) 45 (5HF)	36	36	36	90
Torque Gradient (oz-in/deg) (min)	0.06	0.25	0.40	0.40	1.1	1.1	0.15
Rotor DC Resistance (ohms) (approx)	93	30	13	13	--	--	--
Stator DC Resistance (ohms) (approx)	150	40	24	24	--	--	--
Secondary Load Current (mA) (max)	40	200	350	--	--	--	200
Synchronizing Time (sec) 34° (approx)	1	1	1	1	1	1	1
Synchronizing Time (sec) 179° (approx)	2	2	2	2	2	2	4

TABLE XXIX. Pre-standard synchros of MIL-S-2335 - Continued.

TYPE DESIGNATION	1D 1HD	1DG 1HDG	3DB 3D	3HDG	5DB 5D	5DG 5HDG	6DG 6HDG	7DG 7HDG
Primary voltage (nominal)	90	90	90	90	90	90	90	90
Energizing Current (mA) (max)	300	300	700	700	1000	1000	2000	3500
Energizing Power (watts) (max)	8	8	13	13	15	15	23	30
Secondary Peak (min) Voltage Limits (max)	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8	88.2 91.8
No Load Temp. Rise (°C) (max)	50	50	50	50	50	50	50	50
Electrical Error (minutes) (max)	180	18	81	18	54	18	18	18
Torque Gradient (oz-in/deg) (min)	0.035	0.035	0.15	0.15	0.3	0.3	1.4	4
Rotor DC Resistance (ohms) (approx)	130	157	42	44	18	18	4	1.6
Stator DC Resistance (ohms) (approx)	78	89	32	30	16	15	4	1.3
Drives with Normal Accuracy	--	one 1F	--	--	--	two 5F's, five 1F's twelve 5CT's or 1CT's	six 5F's, twelve 1F's, twenty-four 5CT's or 1CT's	twelve 5F's, twenty-four 1F's, forty eight-5CT's or 1CT's
Secondary Load Current (mA) (max)	20	20	180	180	250	250	800	2000
Synchronizing Time (sec) 34° (approx)	1	--	1	--	1	--	--	--
Synchronizing Time (sec) 179° (approx)	2	--	2	--	2	--	--	--

TABLE XXIX. Pre-standard synchros of MIL-S-2335 - Continued.

TYPE DESIGNATION	1CT 1HCT	3CT 3CTB	5CT 5CTB 5HCT	5SCT	6CT
Primary voltage (nominal)	115	115	115	115	115
Energizing Current (mA)(max)	35	35	35	34	35
Energizing Power (watts)(max)	0.7	0.7	0.7	0.8	0.7
Secondary Peak (min)	54	54	54	54	54
Voltage limits (max)	60	60	60	60	60
No Load Temp. Rise (°C)(max)	50	50	50	50	50
Electrical Error (minutes)(max)	18	18	18	18	18
Friction Torque (oz-in/deg)(min)	0.2	0.2	0.2	0.6	0.4
Rotor DC Resistance (ohms)(approx)	380	160	105	30	
Stator DC Resistance (ohms)(approx)	820	360	234	1.0	1.0
Voltage Gradient (volts/degree)	1.0	1.0	1.0	1.0	1.0

TABLE XXX. General trouble symptoms.

NOTE: Be sure TR is not jammed physically. Turn TX slowly in one direction and observe TR.

SYMPTOMS	TROUBLE
Overhead Indicator lights Units hum at all TX settings One unit overheats TR follows smoothly, but reads wrong	Rotor circuit open or shorted See Table XXXI
Overhead Indicator lights Units hum at all except two opposite TX settings Both units overheat TR stays on one reading half the time, then swings abruptly to the opposite one. TR may oscillate or spin.	Stator circuit shorted See Table XXXII
Overhead Indicator lights Units hum on two opposite TX settings Both units get warm TR turns smoothly in one direction, then reverses	Stator circuit open See Table XXXIII
TR reads wrong or turns backwards, follows TX smoothly	Unit interconnections wrong Unit not zeroed See Tables XXXIV and XXXV

TABLE XXXI. Open or shorted rotor.

NOTE: Set TX to 0° and turn rotor smoothly counterclockwise.

SYMPTOMS	TROUBLE
TR turns counterclockwise from 0° to 180° in a jerky or erratic manner, and gets hot	TX rotor open
TR turns counterclockwise from 0° or 180° in a jerky or erratic manner, and TX gets hot	TR rotor open
TR turns counterclockwise from 90° or 270°, torque is about normal, motor gets hot, and TX fuses blow	TX rotor shorted
TR turns counterclockwise from 90° or 270°, torque is about normal, TX gets hot, and TR fuses blow	TR rotor shorted

TABLE XXXII. Shorted stator.

SYMPTOMS		TROUBLE
When TX is on 120° or 300° but When TX is between 340° and 80°, or between 160° and 260°	Overload Indicator goes out and TR reads correctly Overload Indicator lights, units get hot and hum, and TR stays on 120° or 300°, or may swing suddenly from one point to the other	Stator circuit shorted from S1 to S2
When TX is on 60° or 240° but When TX is between 280° and 20°, or between 100° and 200°	Overload Indicator goes out and TR reads correctly Overload Indicator lights, units get hot and hum, and TR stays on 60° or 240° or may swing suddenly from one point to the other	Stator circuit shorted from S2 to S3
When TX is on 0° or 180° but When TX is between 40° and 140° or between 220° and 320°	Overload Indicator goes out and TR reads correctly Overload Indicator lights, units get hot and hum, and TR stays on 0° or 180°, or may swing suddenly from one point to the other	Stator circuit shorted from S1 to S3
	Overload Indicator on continuously, both units get very hot and hum, and TR does not follow at all or spins	All three stator leads shorted together

TABLE XXXIII. Open stator.

SYMPTOMS		TROUBLE
When TX is on 150° or 330° and When TX is held on 0°	TR reverses or stalls and load Indicator lights TR moves between 300° and 0° in a jerky or erratic manner	S1 stator circuit open
When TX is on 90° or 270° and When TX is held on 0°	TR reverses or stalls and Overload Indicator lights TR moves to 0° or 180°, with fairly normal torque	S2 stator circuit open
When TX is on 30° or 210° and When TX is held on 0°	TR reverses or stalls and Overload Indicator lights TR moves between 0° and 60° in a jerky or erratic manner	S3 stator circuit open
When TX is set at 0°, and then moved smoothly counterclockwise	TR does not follow, no Overload Indication, no hum or overheating	Two or three stator leads open with both rotor circuits open

TABLE XXXIV. Wrong stator connections, rotor wiring correct.

SETTING OR CONDITIONS	INDICATION	TROUBLE
TX set to 0° and rotor turned smoothly counter-clockwise	TR indication is wrong, turns clockwise from 240°	S1 and S2 stator connections are reversed
	TR indication is wrong, turns clockwise from 120°	S2 and S3 stator connections are reversed
	TR indication is wrong, turns clockwise from 0°	S1 and S3 stator connections are reversed
	TR indication is wrong, turns counterclockwise from 120°	S1 is connected to S2, S2 is connected to S3, and S3 is connected to S1
	TR indication is wrong, turns counterclockwise from 240°	S1 is connected to S3, S2 is connected to S1, and S3 is connected to S2

TABLE XXXV. Wrong stator and/or reversed rotor connections.

SETTING OR CONDITIONS	INDICATION	TROUBLE
TX set to 0° and rotor turned smoothly counterclockwise	TR indication is wrong, turns counterclockwise from 180°	Stator connections are correct, but rotor connections are reversed
	TR indication is wrong, turns clockwise from 60°	Stator connections S1 and S2 are reversed, and rotor connections are reversed
	TR indication is wrong, turns clockwise from 300°	Stator connections S2 and S3 are reversed, and rotor connections are reversed
	TR indication is wrong, turns clockwise from 180°	Stator connections S1 and S3 are reversed, and rotor connections are reversed
	TR indication is wrong, turns counterclockwise from 300°	S1 is connected to S2, S2 is connected to S1, S3 is connected to S1, and rotor connections are reversed
	TR indication is wrong, turns counterclockwise from 60°	S1 is connected to S3, S2 is connected to S1, S3 is connected to S2, and rotor connections are reversed

TABLE XXXVI. Size 5 units.

CHARACTERISTICS (Dimensions are in inches)	REQUIREMENTS OF BUSHIPS SPECIFICATIONS TYPES A AND M	BENDIX CAL-3075 CAL-3076	BENDIX CAL-3075-1 CAL-3075-2 CAL-3076-1 CAL-3076-2	HENSCHEL 15-001 15-002 15-014 15-015 15-030*	HENSCHEL 15-021*	BUORD TYPES 5F AND 5G
Diameter of mounting Face-shaft end	———	1.500	1.500	1.875	1.875	1.630
Outside flange dia.	3.625	3.625	3.625	3.625	3.625	3.625
Outside shell dia.	3.390	3.375	3.375	3.390	3.230	3.390
Shaft diameter and description	0.250	0.250	0.3125	0.25 No. 4-48 tap through 1/4" from end	0.3125 No. 6-40 tap through 1/4" from end and keyway 3/8 x 1/16 x 1/32	0.25, threaded on end (1/4" -28, 0.247 dia.)
Overall length to end of shaft	6.050	6.040	6.040	6.050	6.050	6.050
End of shaft to first flange	2.020	2.030	2.030	2.020	2.020	2.020
Width of flange	0.250	0.250	0.250	0.250	0.250	0.250
Distance between flanges, center to center	2.060	2.060	2.060	2.060	2.060	2.070
Secondary voltage	None	90	90	90	90	90
Rotation for 1-2-3 connection, shaft end	None	CW	CW	CW	CW	CCW

*The 15-030 is labeled type A SR (Transmitter) or type M SR (Receiver). (The "SR" stands for "Special Replacement".) It is essentially a type 15-021 unit with a small shaft and a shim fitted between flanges to make it a suitable replacement for the older type Henschel units (15-001, 15-002, 15-014, and 15-015).

Henschel 15-011 units are found on many vessels and are somewhat shorter than the 15-030 units, distances between mounting flanges being 1.750 inches and 2.060 inches; however, a complete 15-030 unit can always be used to replace a complete 15-011 unit. Spare part items for special replacement units will be the same as for current type A and type M units and will not be interchangeable with spare parts originally furnished.

TABLE XXXVII. Size 1 transmitters.

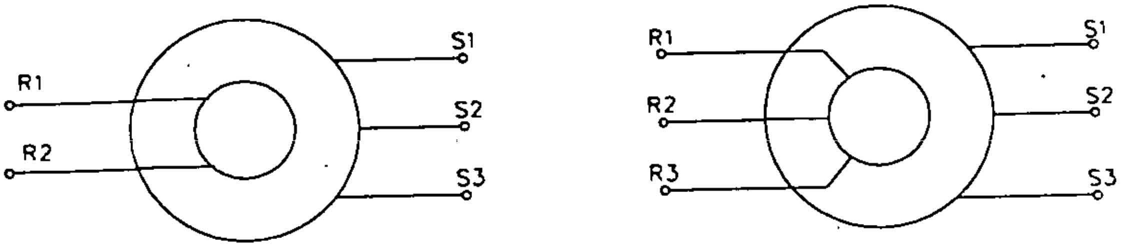
CHARACTERISTICS (Dimensions are in inches)	REQUIREMENTS OF BUSHIPS SPECIFICATIONS TYPE N	BENDIX CAL-4400-1*	HENSCHEL 15-023	BUORD TYPE 1F*
Diameter of mounting:				
Face-shaft end		1.0625		1.0625
		1.250	1.000	1.250
Outside flange dia.	2.375	2.250	2.375	2.250
Outside shell dia.	2.188	1.950	2.188, 2.268 two sec. of shell	1.950
Shaft diameter and description	0.125	0.156	0.1251	0.182 shaft tapered threaded on end No. 2-64 NF3 0.086 diameter
Overall length to end of shaft	3.969	3.938	3.969	3.900
End of shaft to first flange	1.063	2.192	1.063	2.140
Width of flange	0.250	0.250	0.250	0.250
Distance between flanges, center to center	1.196	Only one flange	1.196	Only one flange
Secondary voltage	None	90	90	90
Rotation for 1-2-3 connection shaft end	None	CCW	CW	CCW

*The Bendix CAL-4400-1 is identical, except for shaft size, with a type 1F synchro. When used with a type A or B transmitter, S1 and S3 must be reversed for normal rotation.

TABLE XXXVIII. Size 6 transmitters.

CHARACTERISTICS (Dimensions are in inches)	REQUIREMENTS OF BUSHIPS SPECIFICATIONS	BENDIX CAL-3482	HENSCHEL 15-022*	BUORD TYPE 6G
Diameter of mounting:				
Face-shaft end		1.625	2.000	1.625
Outside flange dia.	4.500	4.500	4.500	4.500
Outside shell dia.	4.000	Approx. 4, 4.250 to step on flange	4.000	4.080
Shaft diameter and description	0.350	0.350	0.350	0.350 shaft tapered threaded on end 1/4"-28 NF3 keyway 5/16 x 0.0937 x 3/32
Overall length to end of shaft	7.220	7.167	7.094	7.220
End of shaft to first flange	2.220	2.220	2.220	2.220
Width of flange	0.250	0.250	0.250	0.250
Distance between flanges, center to center	2.500	2.500	2.500	2.500
Secondary voltages	None	90	90	90
Rotation for 1-2-3 connection shaft end	None	CW	CW	CCW

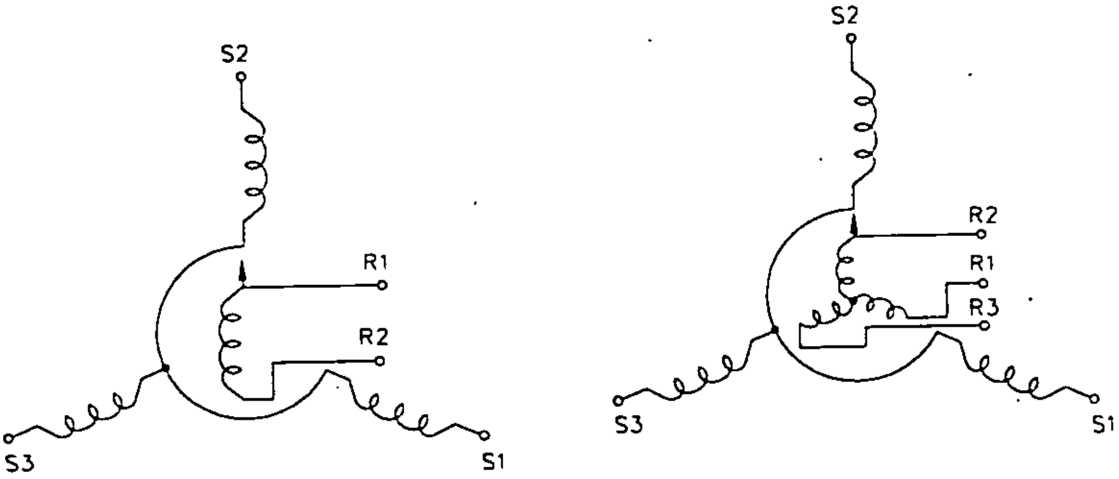
*Will handle up to 18 Type M 1C Receivers without overload.



TRANSMITTERS, RECEIVERS
CONTROL TRANSFORMERS

DIFFERENTIALS

FIGURE 1. Schematic symbols used to show external connections.



CONTROL TRANSFORMERS,
TRANSMITTERS AND
RECEIVERS

DIFFERENTIALS

FIGURE 2. Schematic symbols for relative positions of windings.

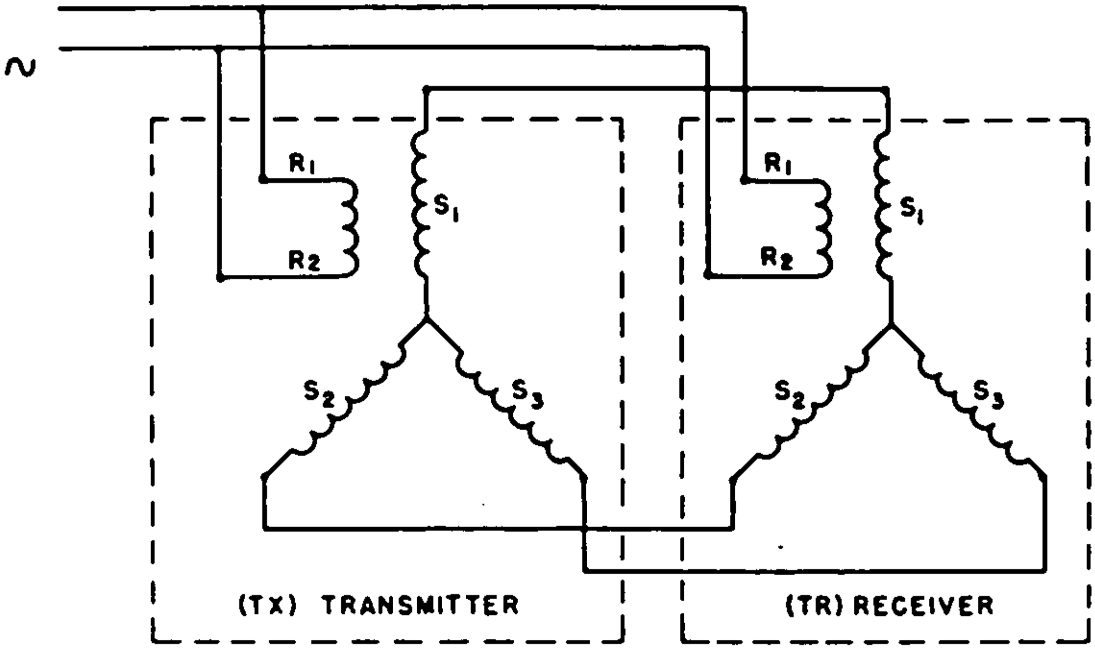


FIGURE 3. Simple torque system.

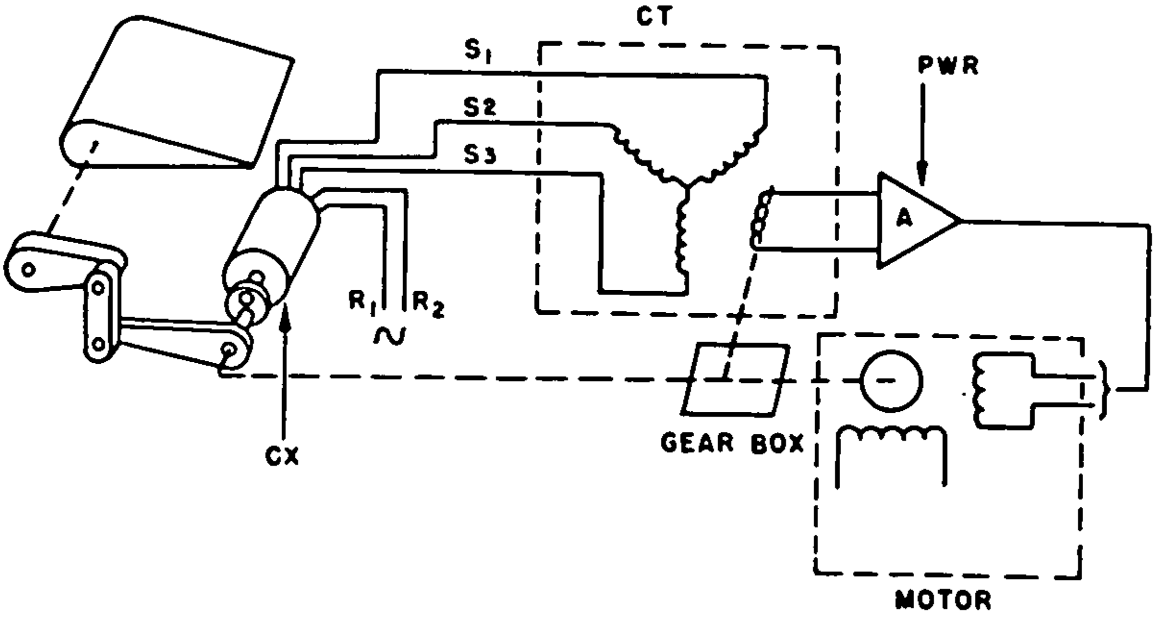


FIGURE 4. Simple control system.

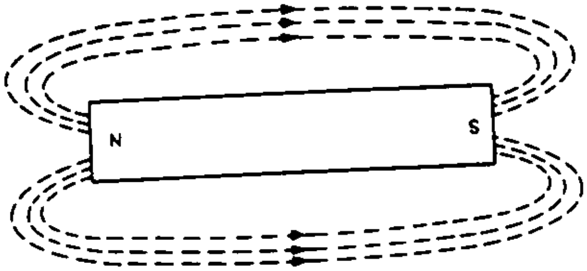


FIGURE 5. Bar magnet and its field.

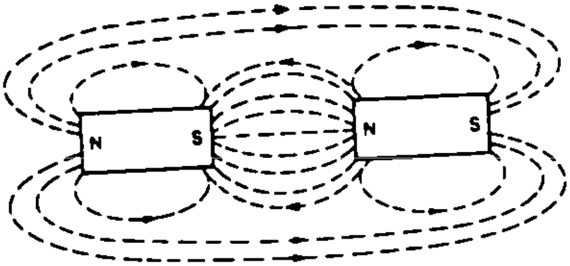


FIGURE 6. Magnetic attraction.

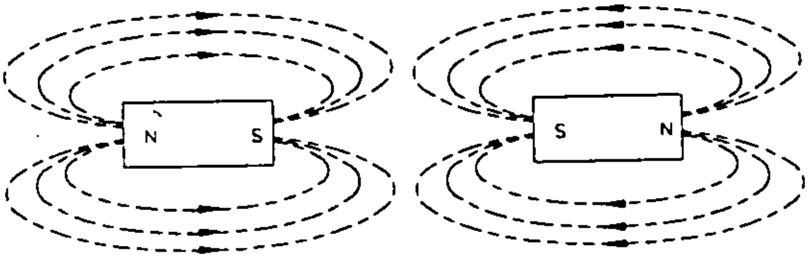


FIGURE 7. Magnetic repulsion.

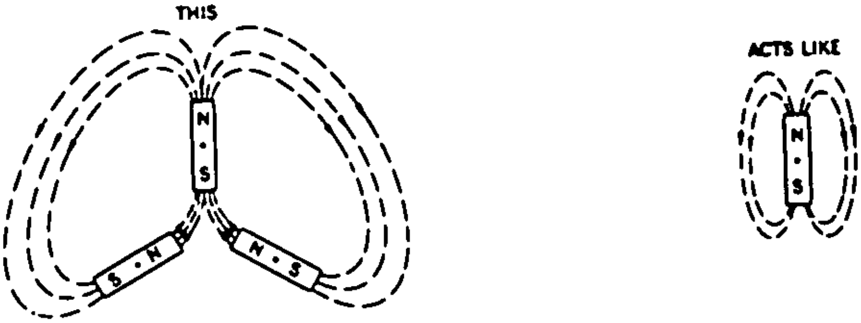


FIGURE 8. Three magnets acting as one.

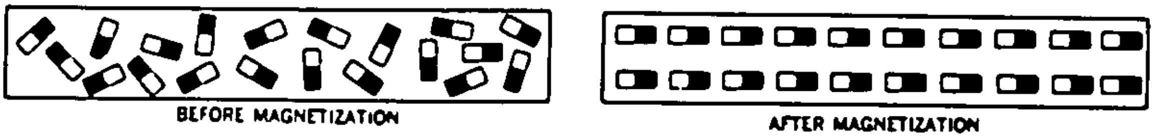


FIGURE 9. Molecular arrangement.

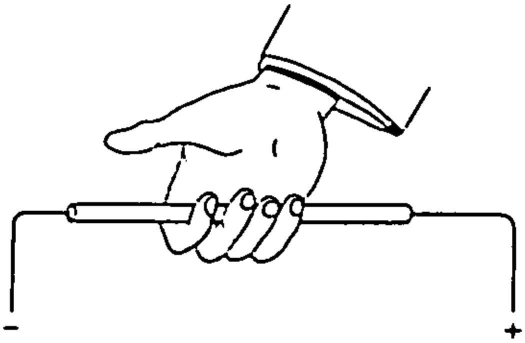


FIGURE 10. Magnetic field around conductor.

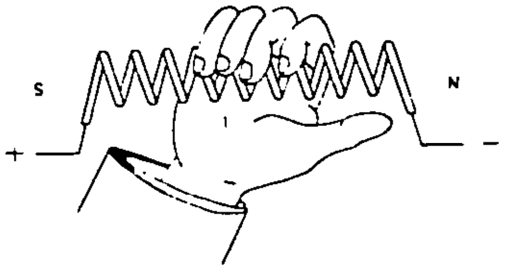


FIGURE 11. Magnetic field around coil.

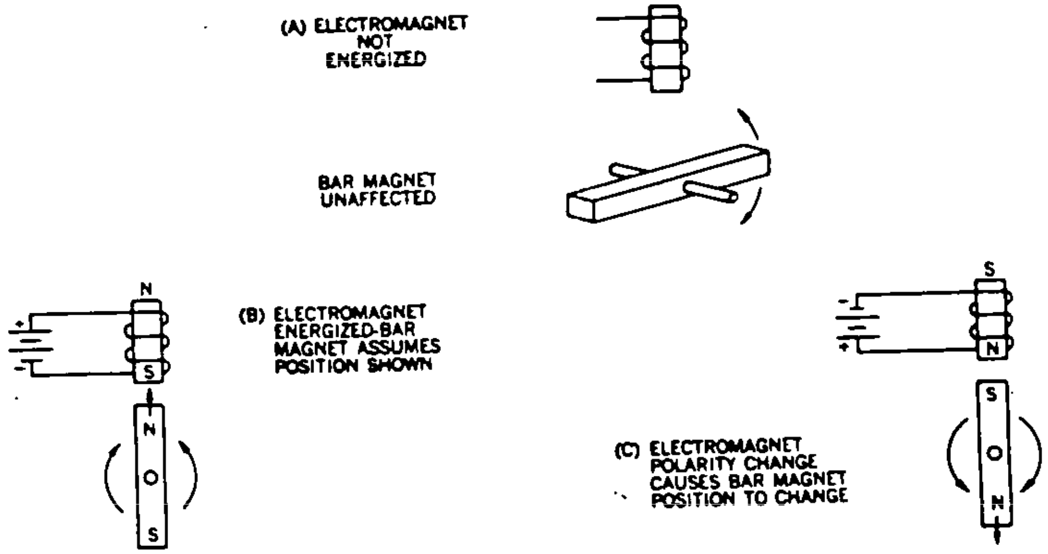

(A) ELECTROMAGNET NOT ENERGIZED
BAR MAGNET UNAFFECTED
N
S
N
O
S
(B) ELECTROMAGNET ENERGIZED-BAR MAGNET ASSUMES POSITION SHOWN
S
N
S
O
N
(C) ELECTROMAGNET POLARITY CHANGE CAUSES BAR MAGNET POSITION TO CHANGE

FIGURE 12. Positioning bar magnet with one electromagnet.

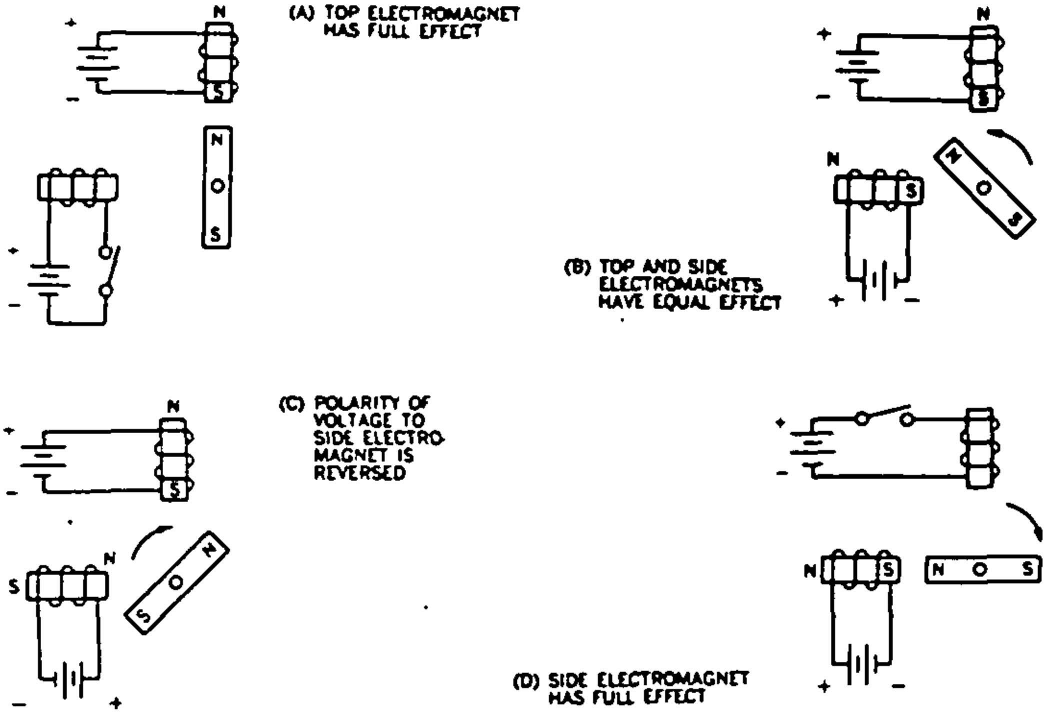

(A) TOP ELECTROMAGNET HAS FULL EFFECT
(B) TOP AND SIDE ELECTROMAGNETS HAVE EQUAL EFFECT
(C) POLARITY OF VOLTAGE TO SIDE ELECTRO-MAGNET IS REVERSED
(D) SIDE ELECTROMAGNET HAS FULL EFFECT
N
S
N O S
+
-

FIGURE 13. Positioning bar magnet with two electromagnets.

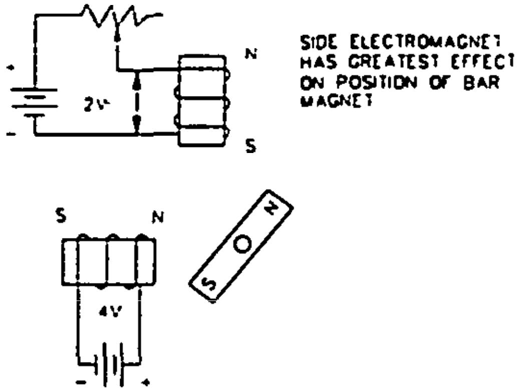

SIDE ELECTROMAGNET HAS GREATEST EFFECT ON POSITION OF BAR MAGNET
2V
4V
N
S
N O S
+
-

FIGURE 14. Positioning bar magnet with two electromagnets of different strength.

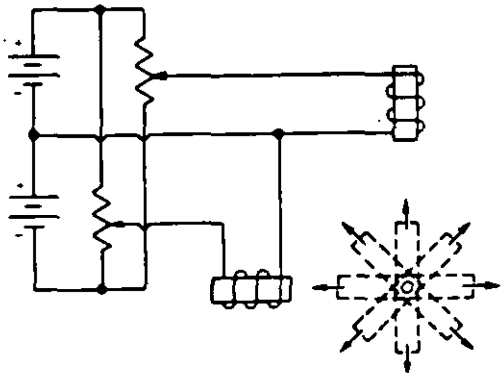


FIGURE 15. Positioning bar magnet with two electromagnets of variable strength.

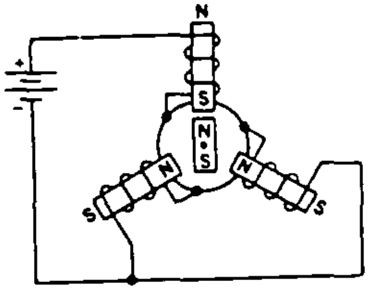


FIGURE 16. Bar magnet with three electromagnets.

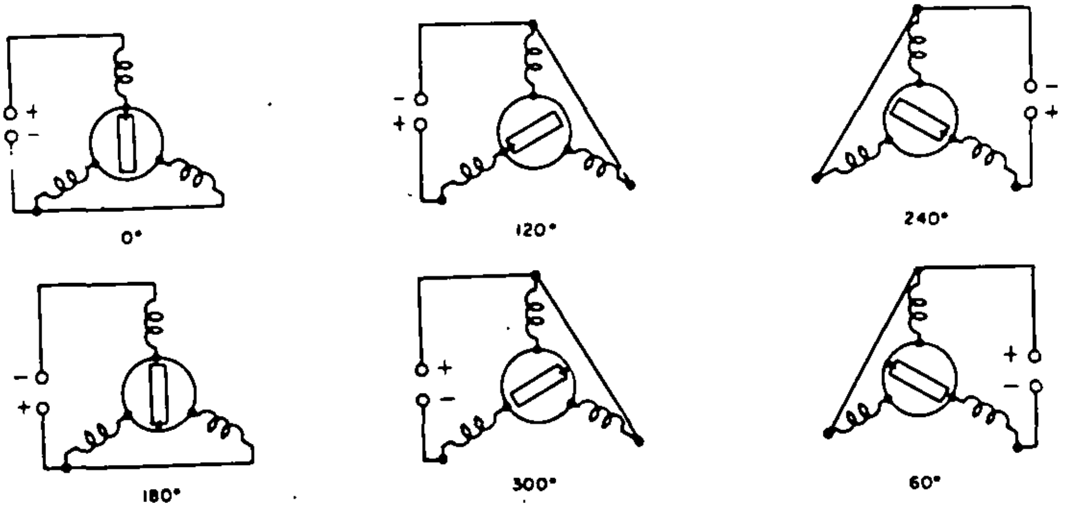


FIGURE 17. Positioning bar magnet with three electromagnets by applying voltage between one coil and the other two.

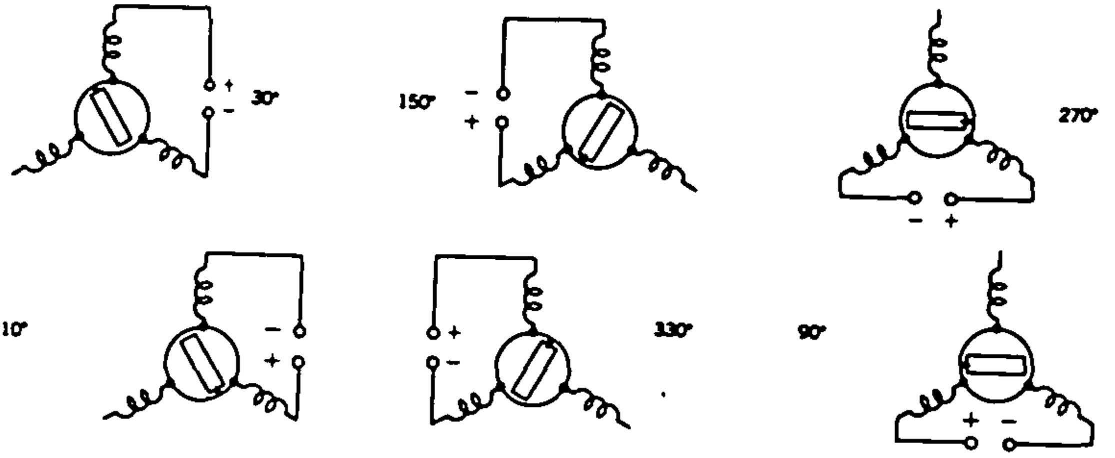


FIGURE 18. Positioning bar magnet with three electromagnets by applying voltage between two of the three coils.

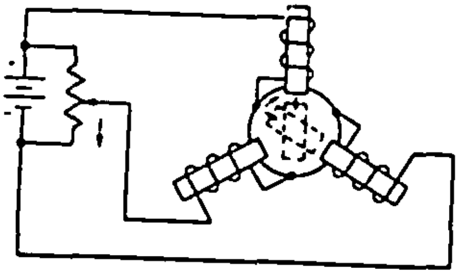
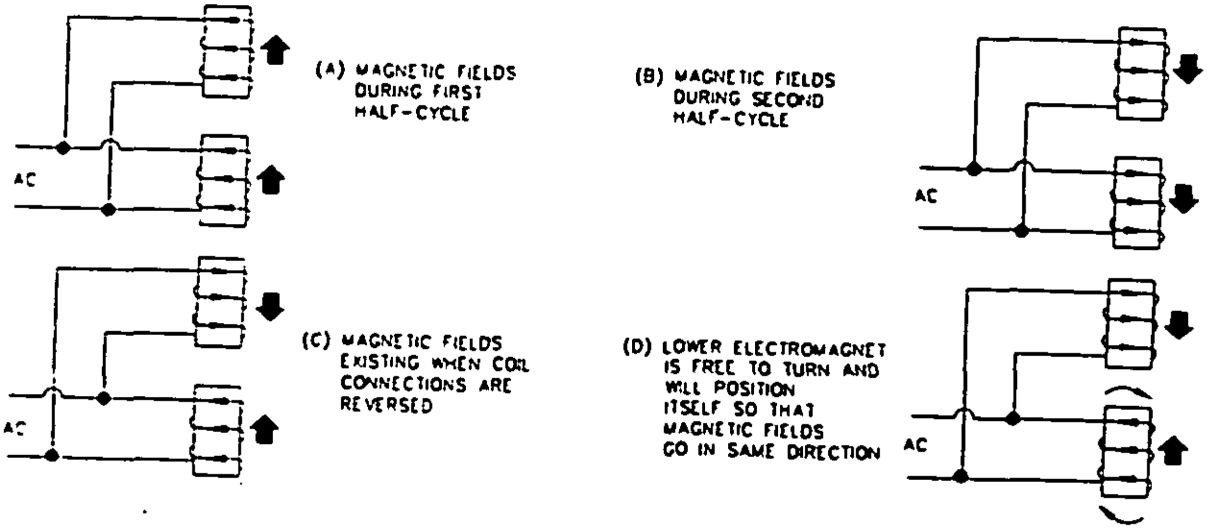


FIGURE 19. Positioning bar magnet with three electromagnets with fixed voltage applied to two coils and variable voltage applied to the third.



(A) MAGNETIC FIELDS DURING FIRST HALF-CYCLE

(B) MAGNETIC FIELDS DURING SECOND HALF-CYCLE

(C) MAGNETIC FIELDS EXISTING WHEN COIL CONNECTIONS ARE REVERSED

(D) LOWER ELECTROMAGNET IS FREE TO TURN AND WILL POSITION ITSELF SO THAT MAGNETIC FIELDS GO IN SAME DIRECTION

FIGURE 20. Electromagnet replaces bar magnet.

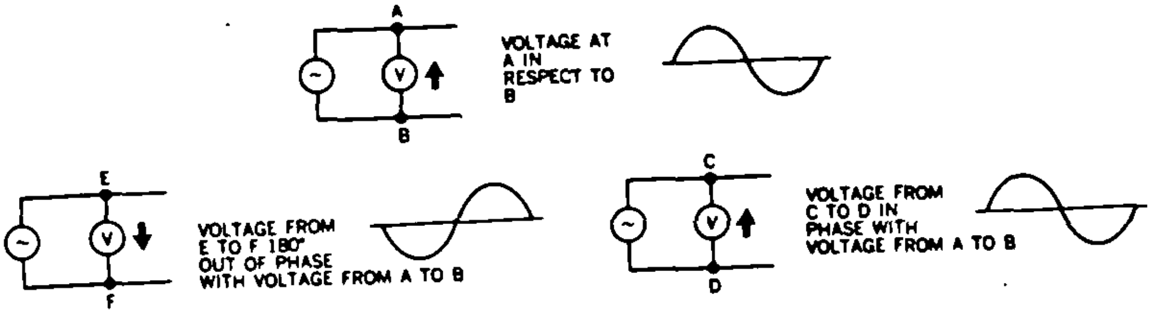


FIGURE 21. Phase relationships.

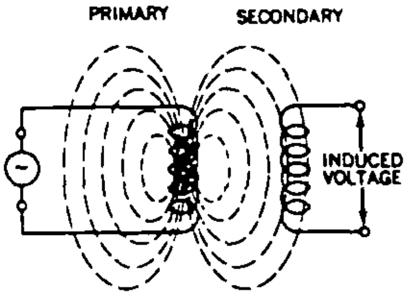


FIGURE 22. Basic transformer.

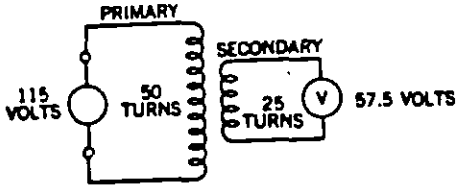
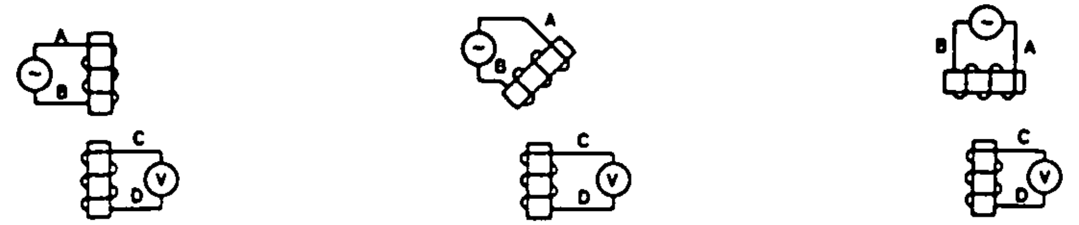


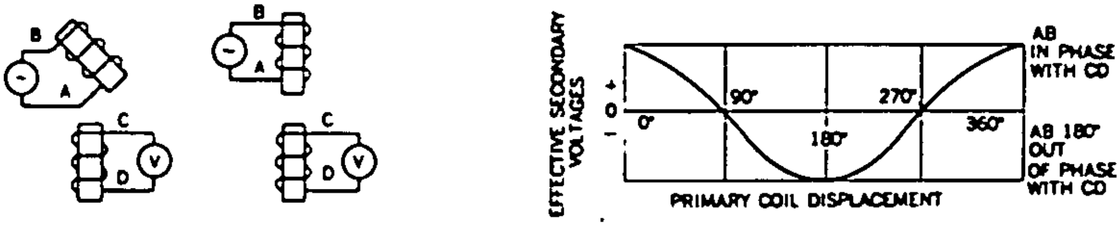
FIGURE 23. Transformation ratio.



(A) COILS ALIGNED (MAXIMUM COUPLING)

(B) 45° DIFFERENCE

(C) COILS AT RIGHT ANGLES (MINIMUM COUPLING)



(D) AND (E) FLUX LINKAGES REVERSED

(F) INDUCED VOLTAGE VS. DISPLACEMENT

FIGURE 24. Transformer with rotatable primary.

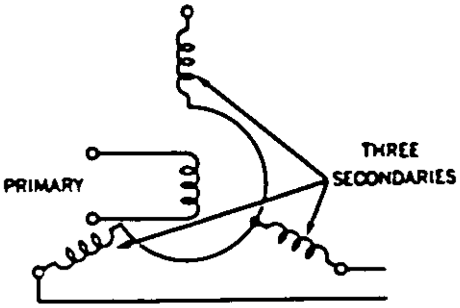


FIGURE 25. Transformer with one primary winding and three secondary windings.

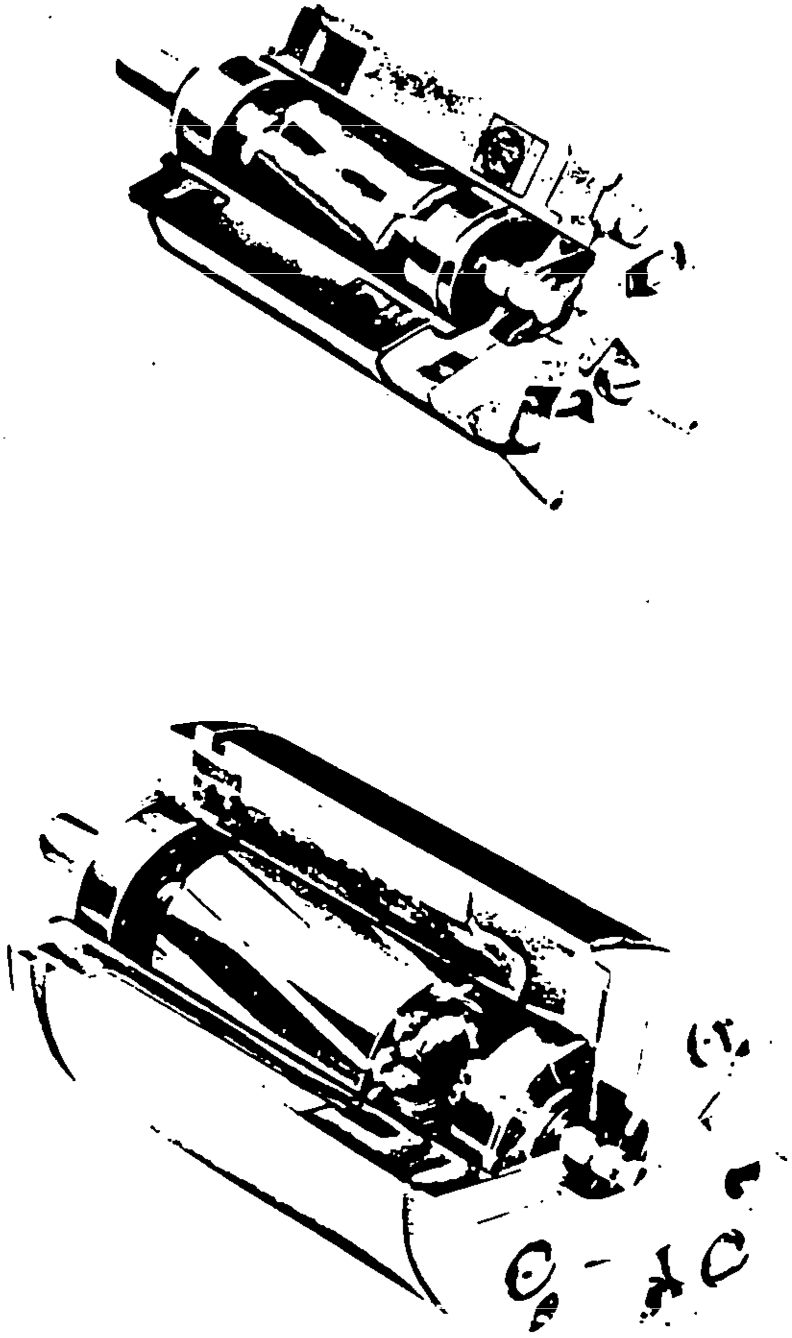


FIGURE 26. Cutaway view of typical synchros.

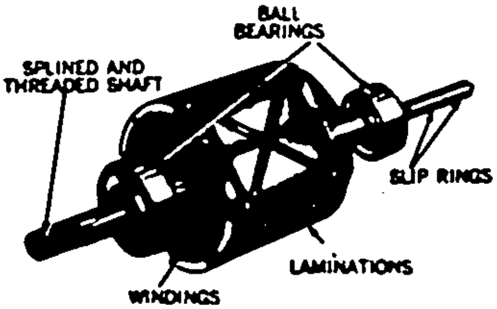


FIGURE 27. Salient pole rotor.

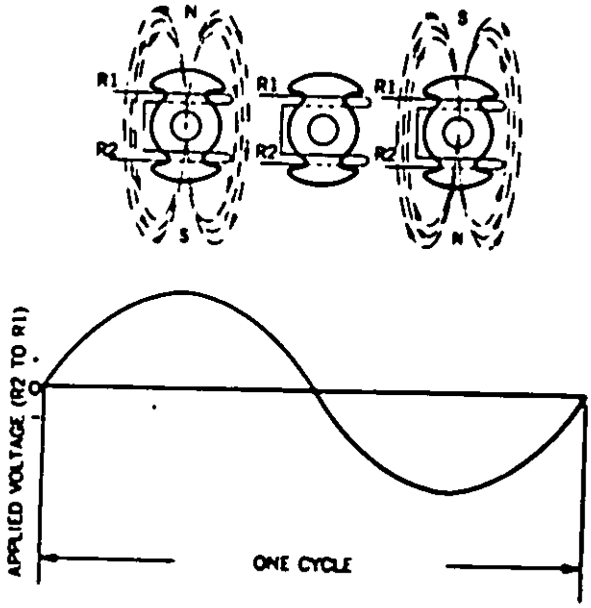


FIGURE 28. Magnetic polarity variations in salient pole rotor.

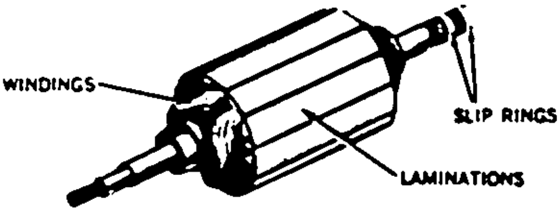


FIGURE 29. Drum or wound rotor.

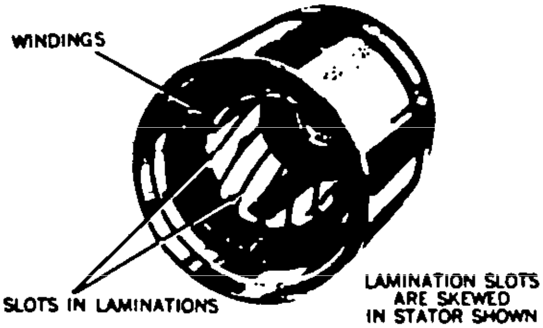


FIGURE 30. Typical stator.

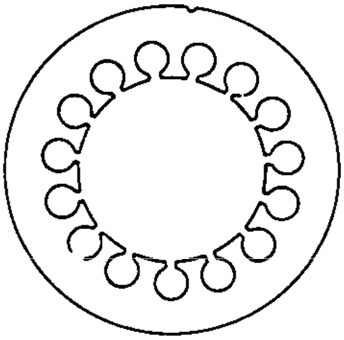


FIGURE 31. Stator lamination.

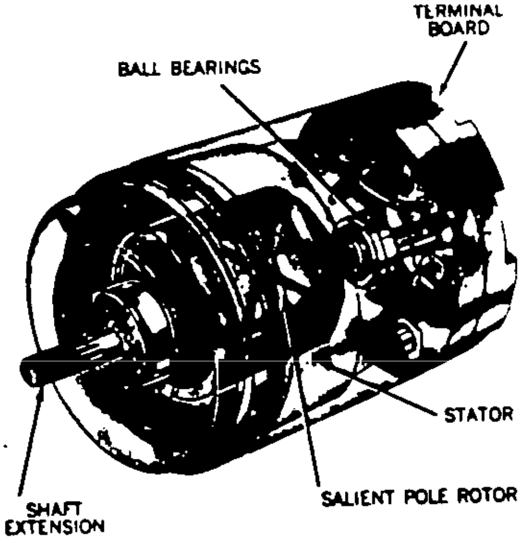


FIGURE 32. Phantom view of synchro transmitter or receiver.

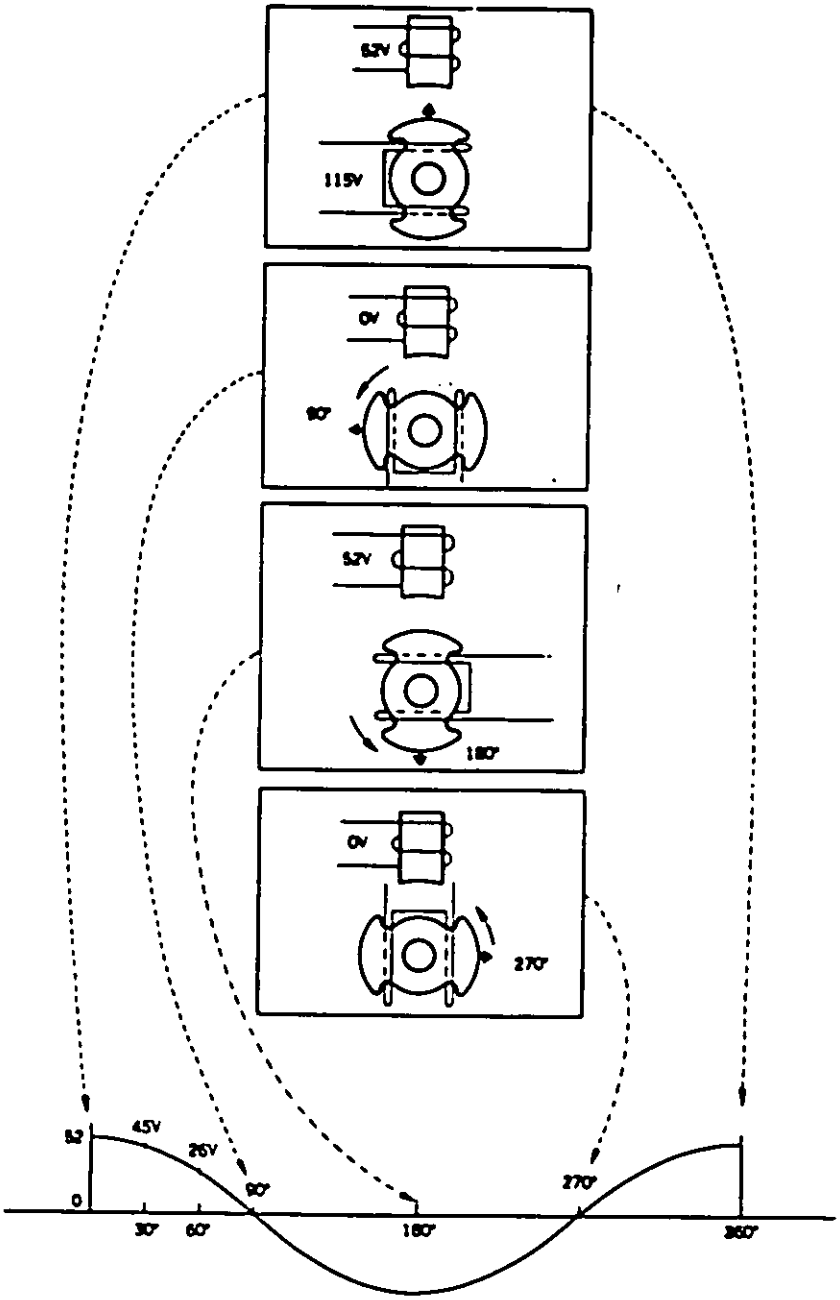


FIGURE 33. Stator voltage vs rotor position.

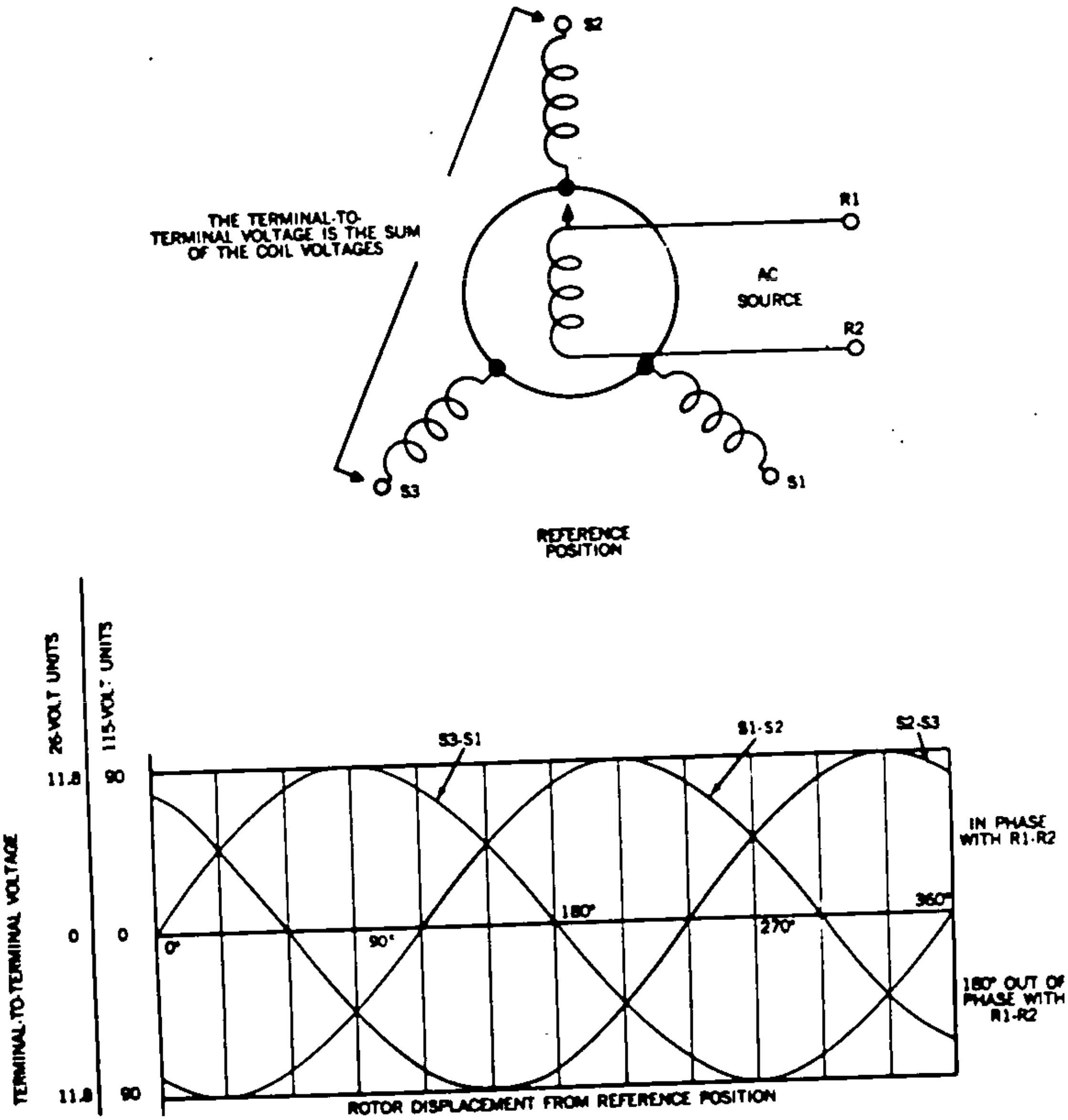

S2
R1
THE TERMINAL-TO-TERMINAL VOLTAGE IS THE SUM OF THE COIL VOLTAGES
AC SOURCE
R2
S3
S1
REFERENCE POSITION
TERMINAL-TO-TERMINAL VOLTAGE
26-VOLT UNITS
115-VOLT UNITS
11.8
90
0
0
11.8
90
S3-S1
S1-S2
S2-S3
0°
90°
180°
270°
360°
IN PHASE WITH R1-R2
180° OUT OF PHASE WITH R1-R2
ROTOR DISPLACEMENT FROM REFERENCE POSITION

FIGURE 34. Terminal-to-terminal voltages.

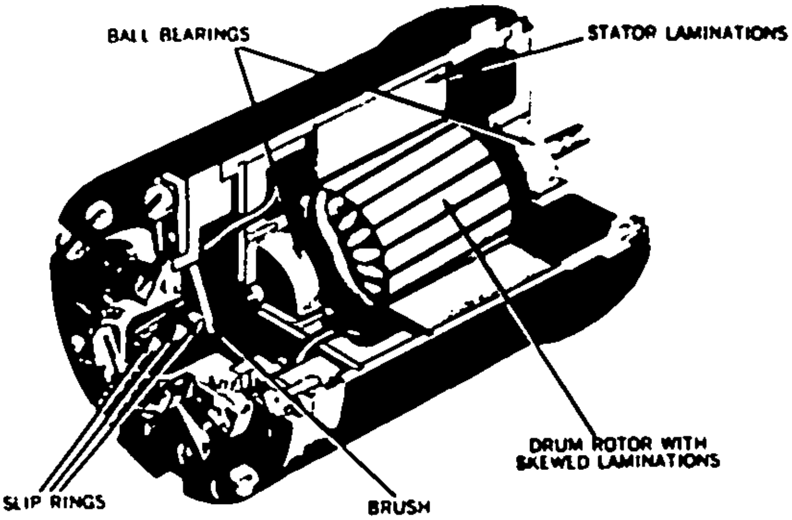


FIGURE 35. Cutaway view of typical synchro differential.

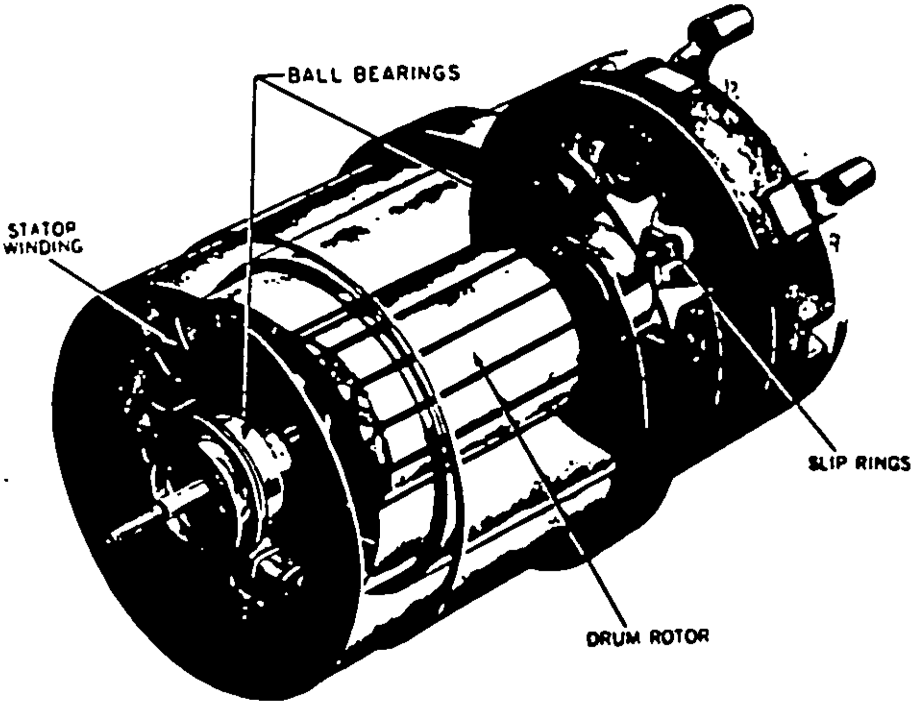


FIGURE 36. Phantom view of typical control transformer.

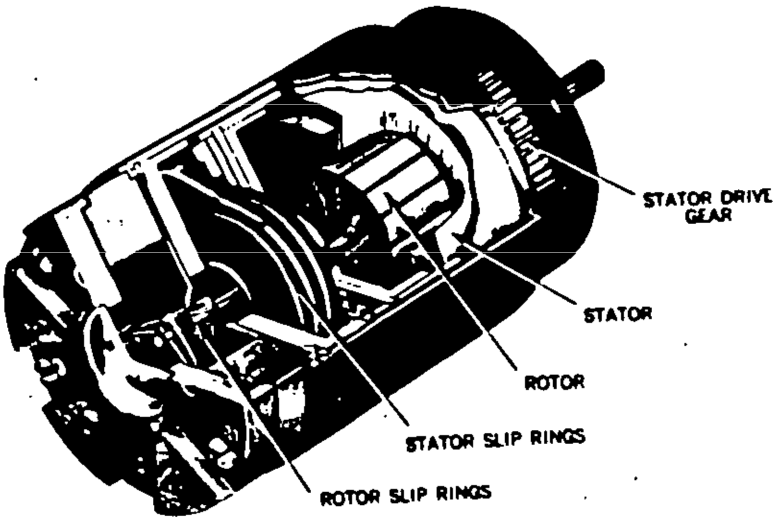


FIGURE 37. Control transformer with rotatable stator.

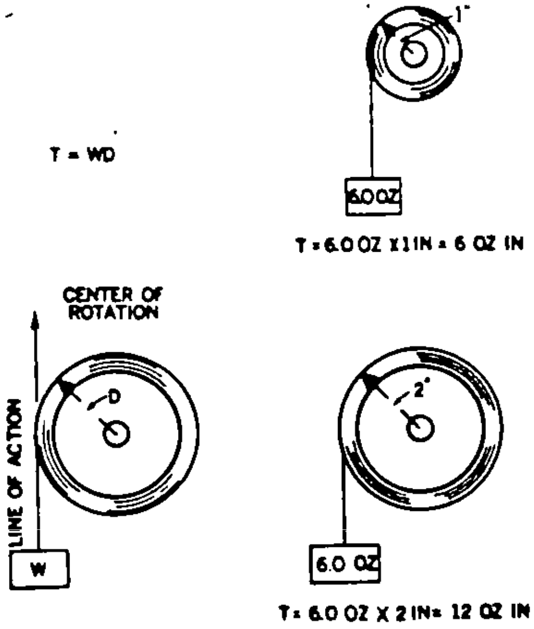


FIGURE 38. Calculated torque.

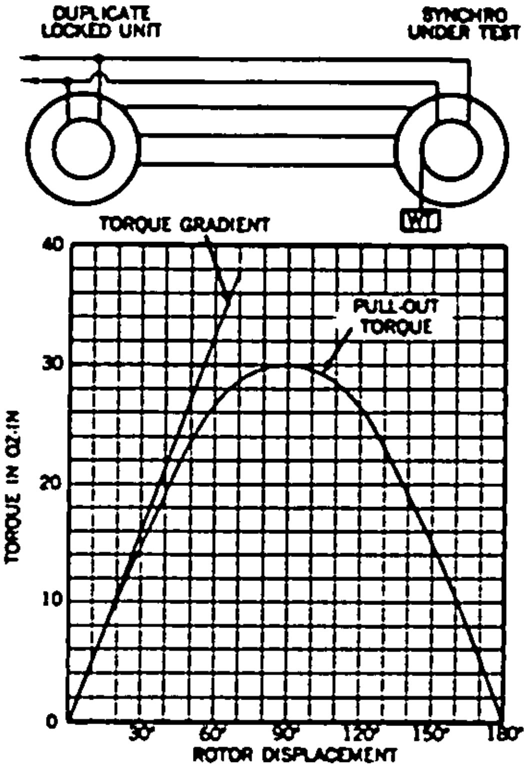


FIGURE 39. Measuring unit torque gradient.

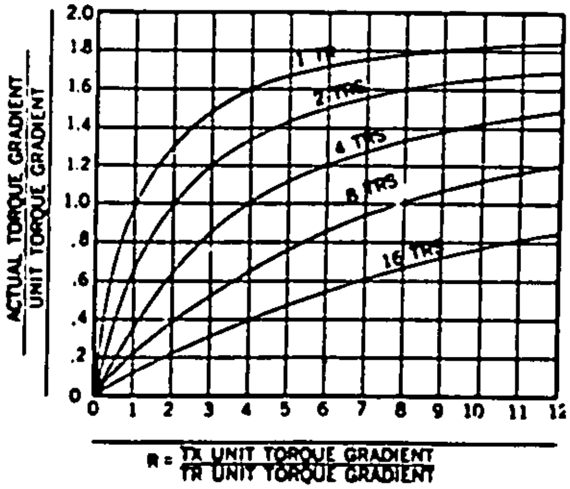


FIGURE 40. Estimating actual torque gradient.

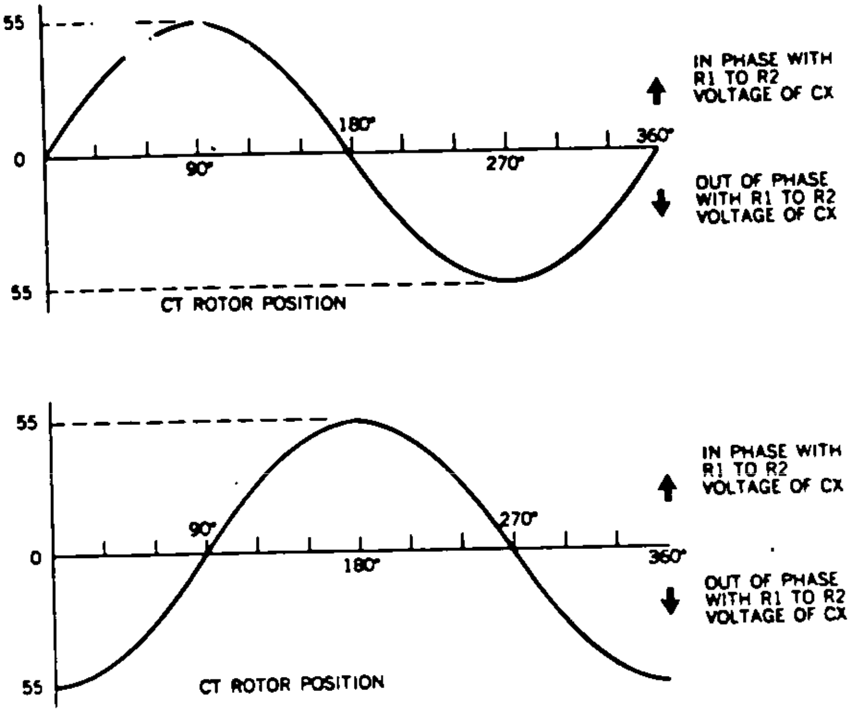


FIGURE 41. Control transformer output voltage.

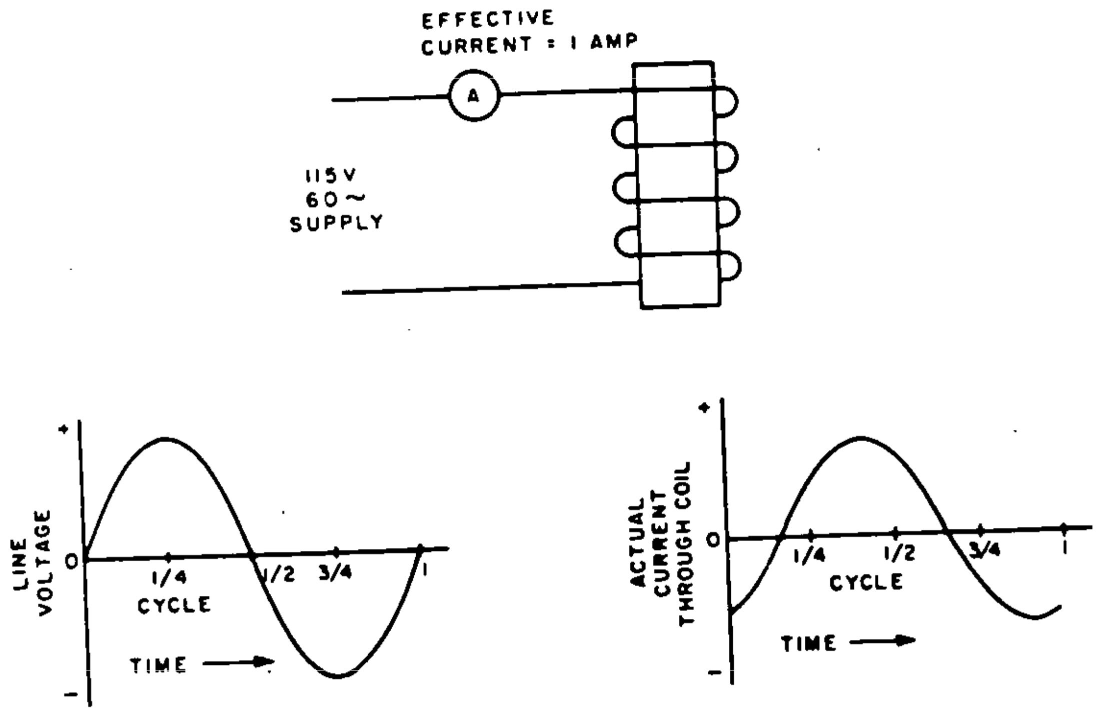


FIGURE 42. Current effect drawn by coil.

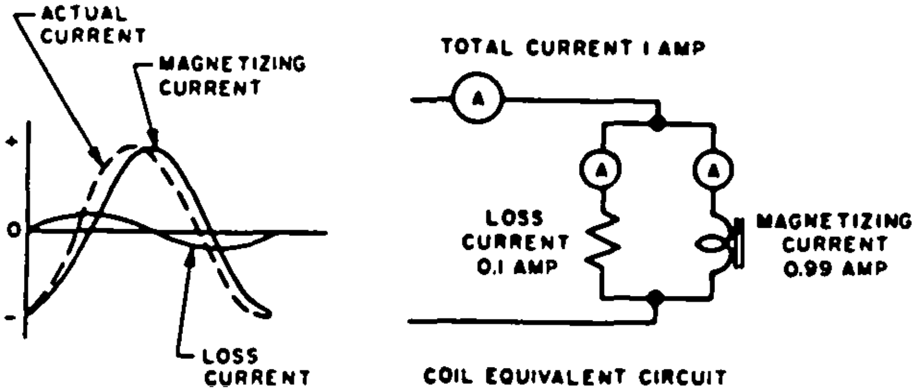
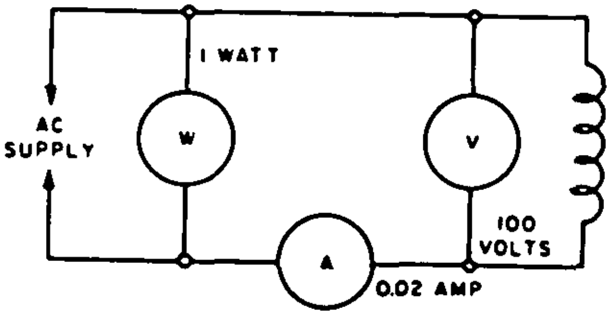


FIGURE 43. Coil currents.



POWER FACTOR = $\frac{W}{VA}$ x 100%

WHERE: W IS THE ACTUAL POWER MEASURED BY THE WATTMETER
V IS THE INDICATED VOLTAGE
A IS THE INDICATED CURRENT

IN THE ILLUSTRATION,

POWER FACTOR = $\frac{1}{100 \times 0.02}$ x 100% = 50%

FIGURE 44. Power factor.

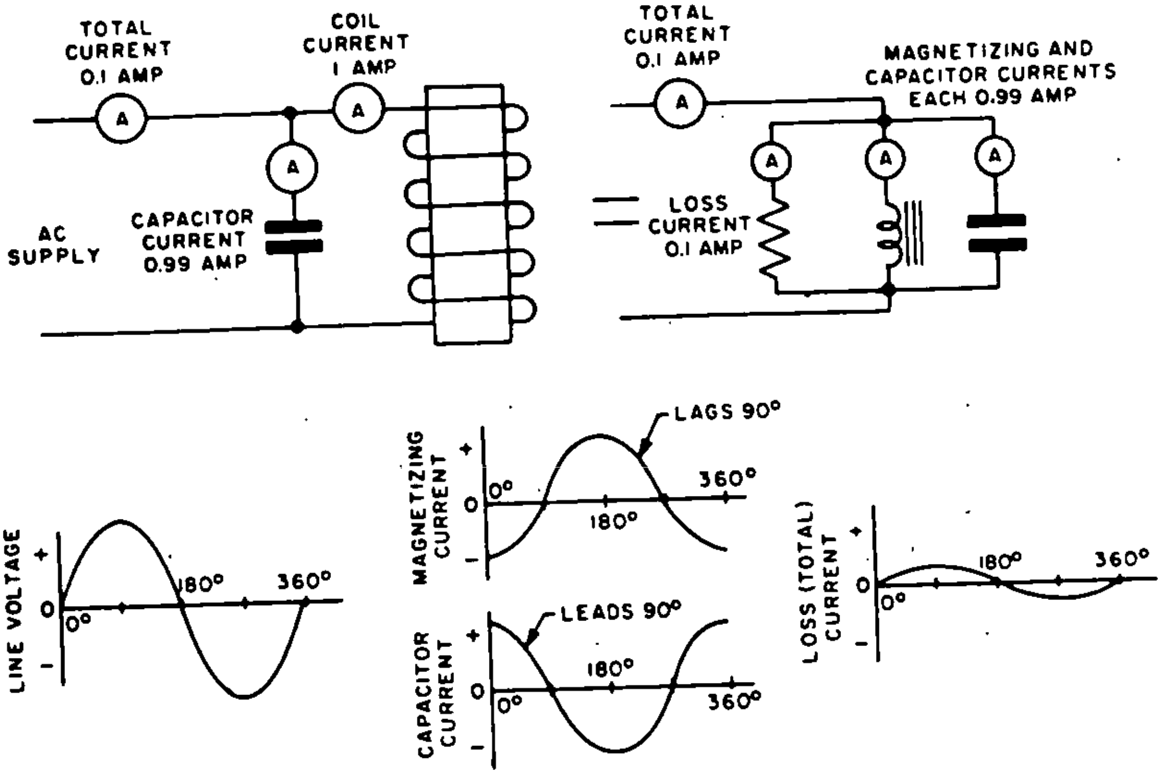


FIGURE 45. Effect of capacitor on coil currents.

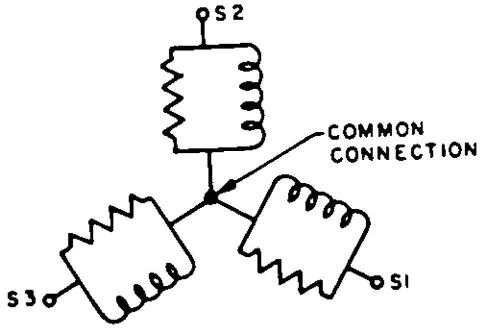


FIGURE 46. Control transformer stator windings.

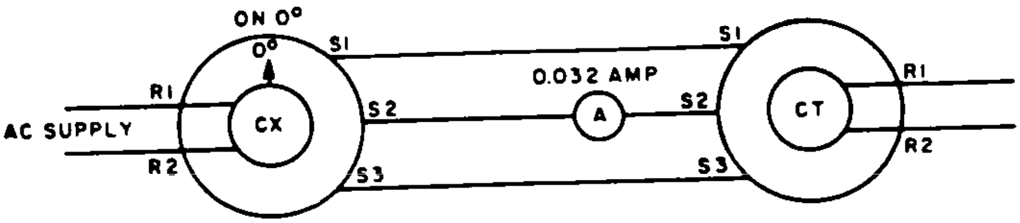


FIGURE 47. Control synchro system (CX-CT).

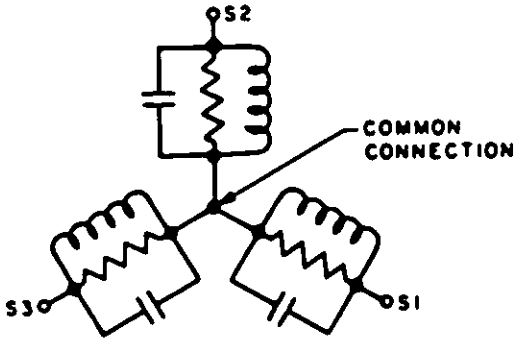


FIGURE 48. Control transformer stator windings with capacitors.

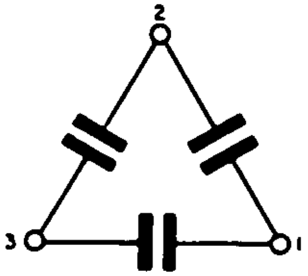


FIGURE 49. Delta-connected capacitors.

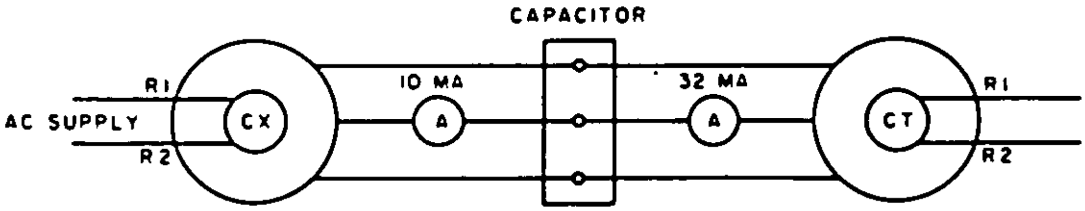
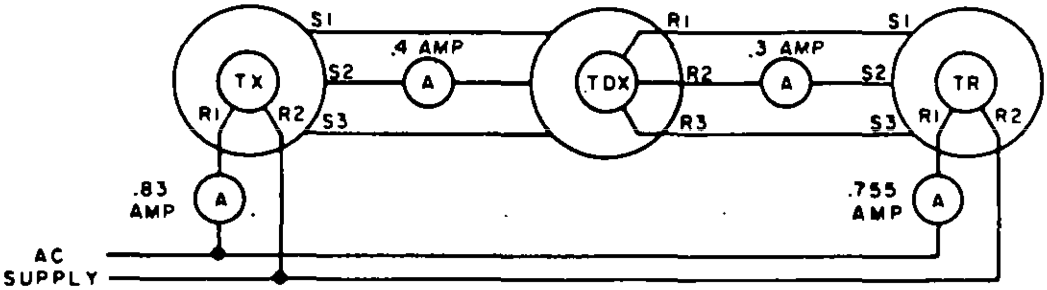
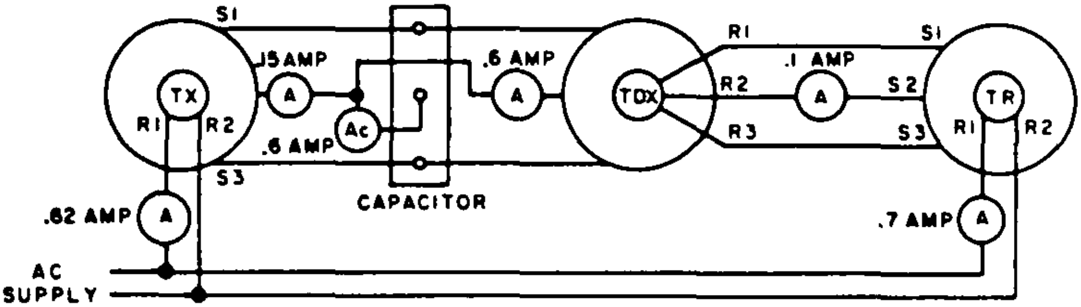


FIGURE 50. Control synchro system with synchro capacitor.



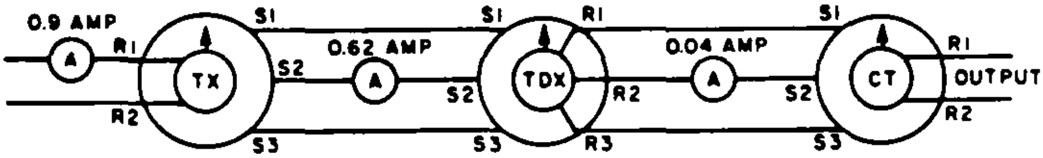
LOSS AND MAGNETIZATION CURRENT FOR DIFFERENTIAL MUST COME THROUGH TRANSMITTER AND RECEIVER

FIGURE 51. TX-TDX-TR system without synchro capacitor.



CAPACITOR CANCELS MAGNETIZATION CURRENT OF DIFFERENTIAL

FIGURE 52. TX-TDX-TR system with synchro capacitor.



TRANSMITTER SUPPLIES EXCITATION CURRENTS FOR BOTH UNITS

FIGURE 53. TX-TDX-CT system without synchro capacitor.

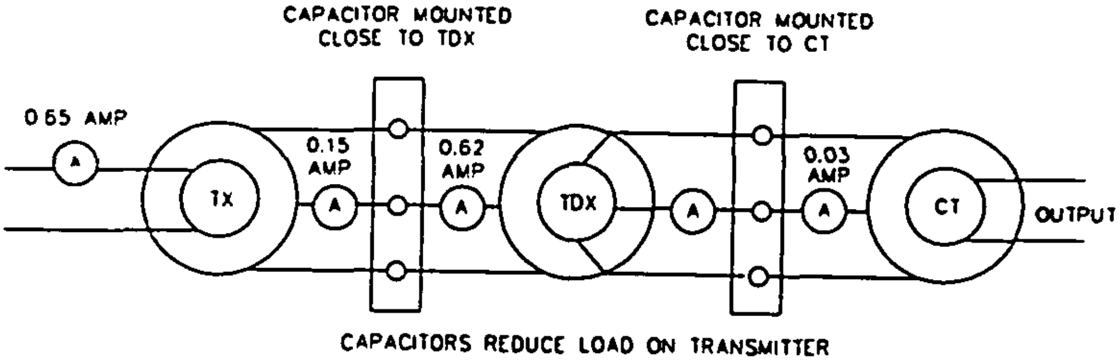

CAPACITOR MOUNTED CLOSE TO TDX
CAPACITOR MOUNTED CLOSE TO CT
0.65 AMP
A
TX
0.15 AMP
A
0.62 AMP
A
TDX
A
0.03 AMP
A
CT
OUTPUT
CAPACITORS REDUCE LOAD ON TRANSMITTER

FIGURE 54. Use of synchro capacitors in TX-TDX-CT system.

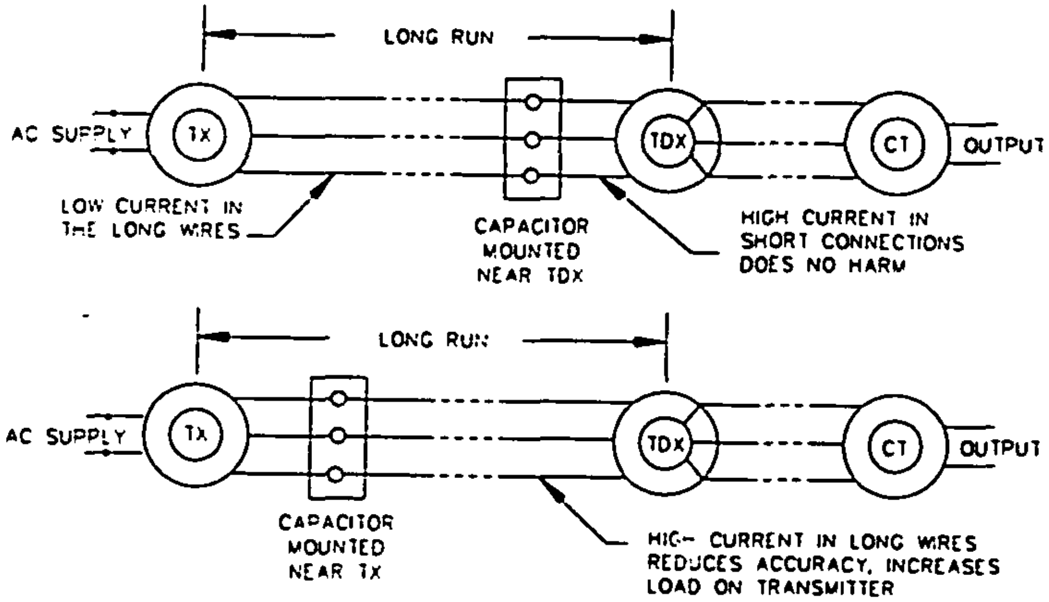

LONG RUN
AC SUPPLY
TX
TDX
CT
OUTPUT
LOW CURRENT IN THE LONG WIRES
CAPACITOR MOUNTED NEAR TDX
HIGH CURRENT IN SHORT CONNECTIONS DOES NO HARM
LONG RUN
AC SUPPLY
TX
TDX
CT
OUTPUT
CAPACITOR MOUNTED NEAR TX
HIGH CURRENT IN LONG WIRES REDUCES ACCURACY, INCREASES LOAD ON TRANSMITTER

FIGURE 55. Location of synchro capacitor in TX-TDX-CT system.

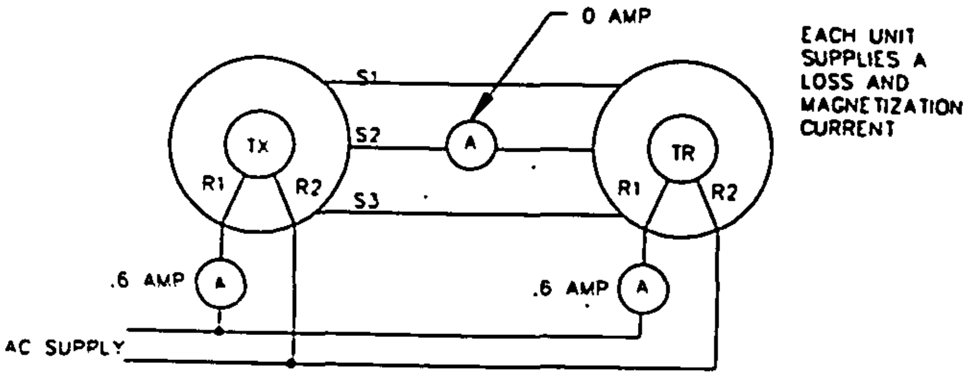


FIGURE 56. TX-TR system without synchro capacitors.

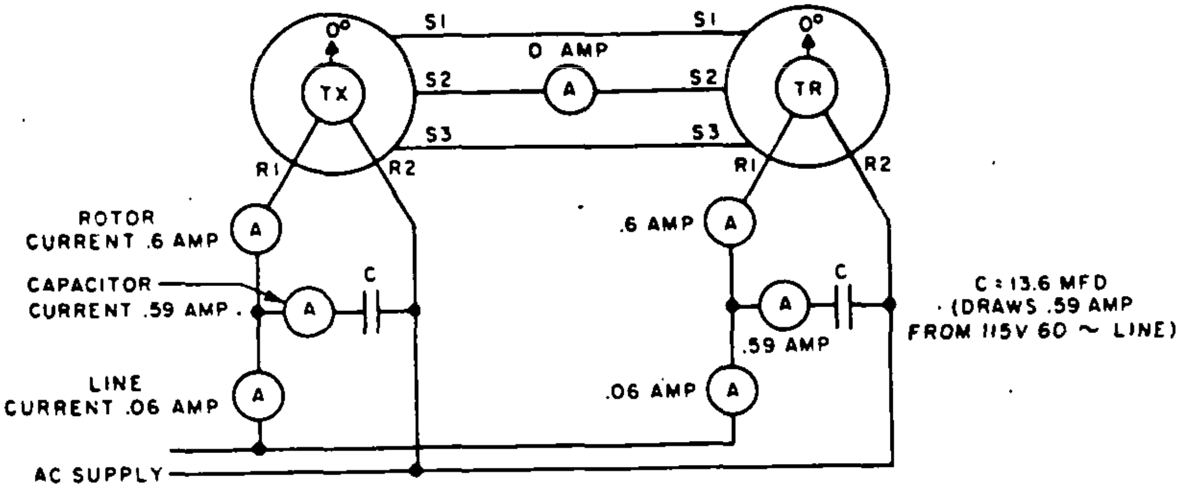


FIGURE 57. TX-TR system with synchro capacitor across rotor leads.

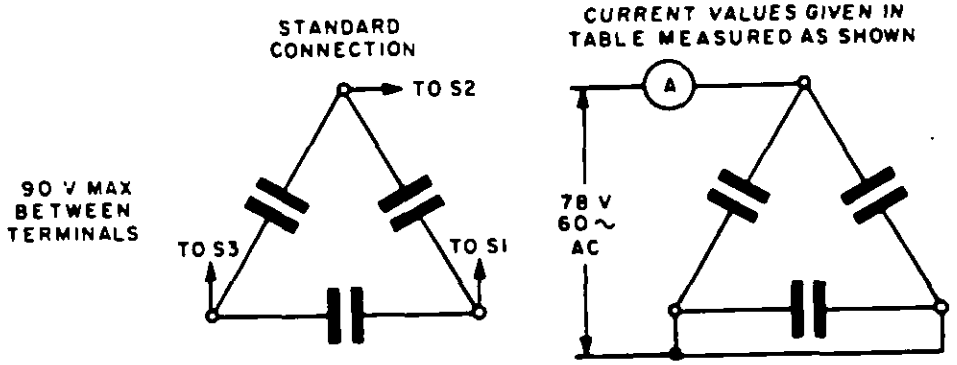

STANDARD CONNECTION
TO S2
TO S3
TO S1
90 V MAX BETWEEN TERMINALS
CURRENT VALUES GIVEN IN TABLE MEASURED AS SHOWN
A
78 V
60 ~
AC

FIGURE 58. Connections and current values of capacitors in Table IV.

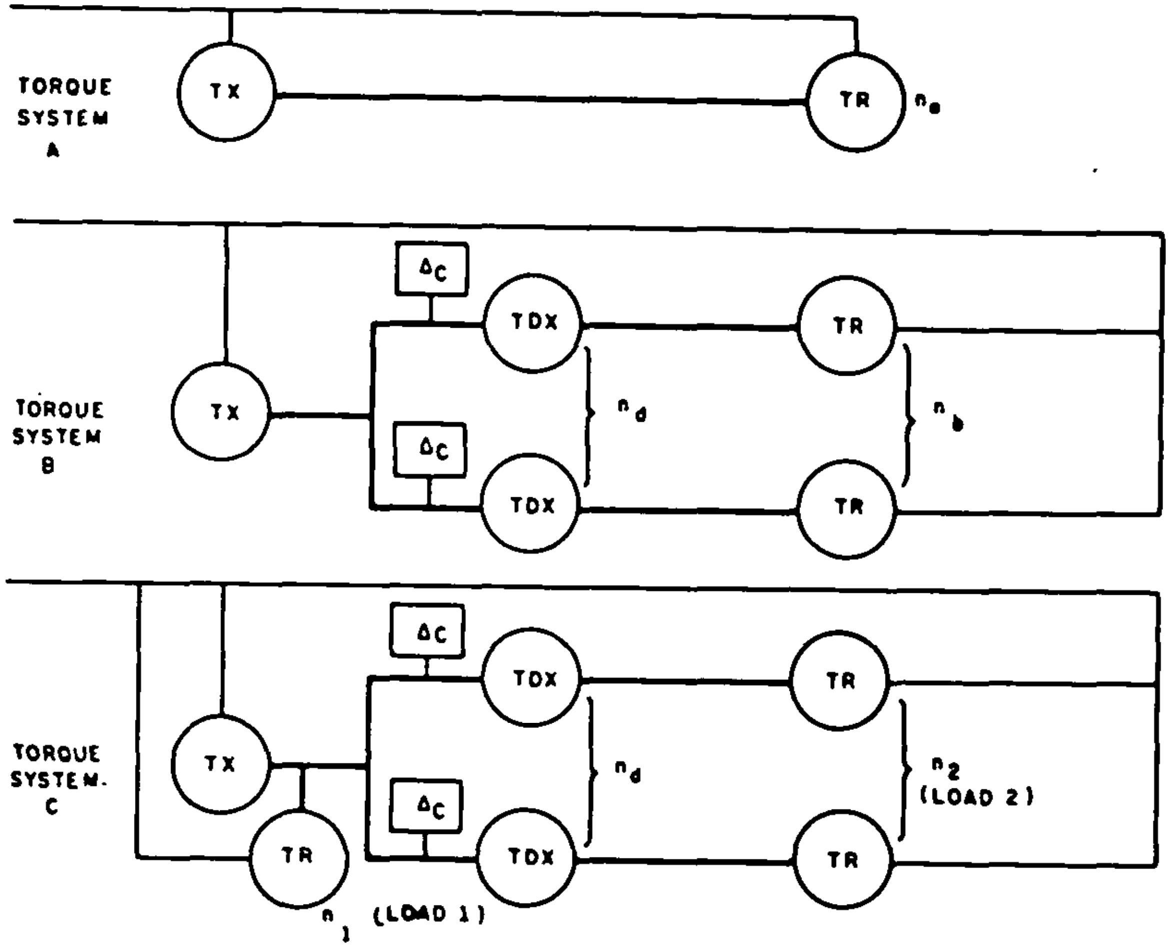


FIGURE 59. System designation key for torque systems.

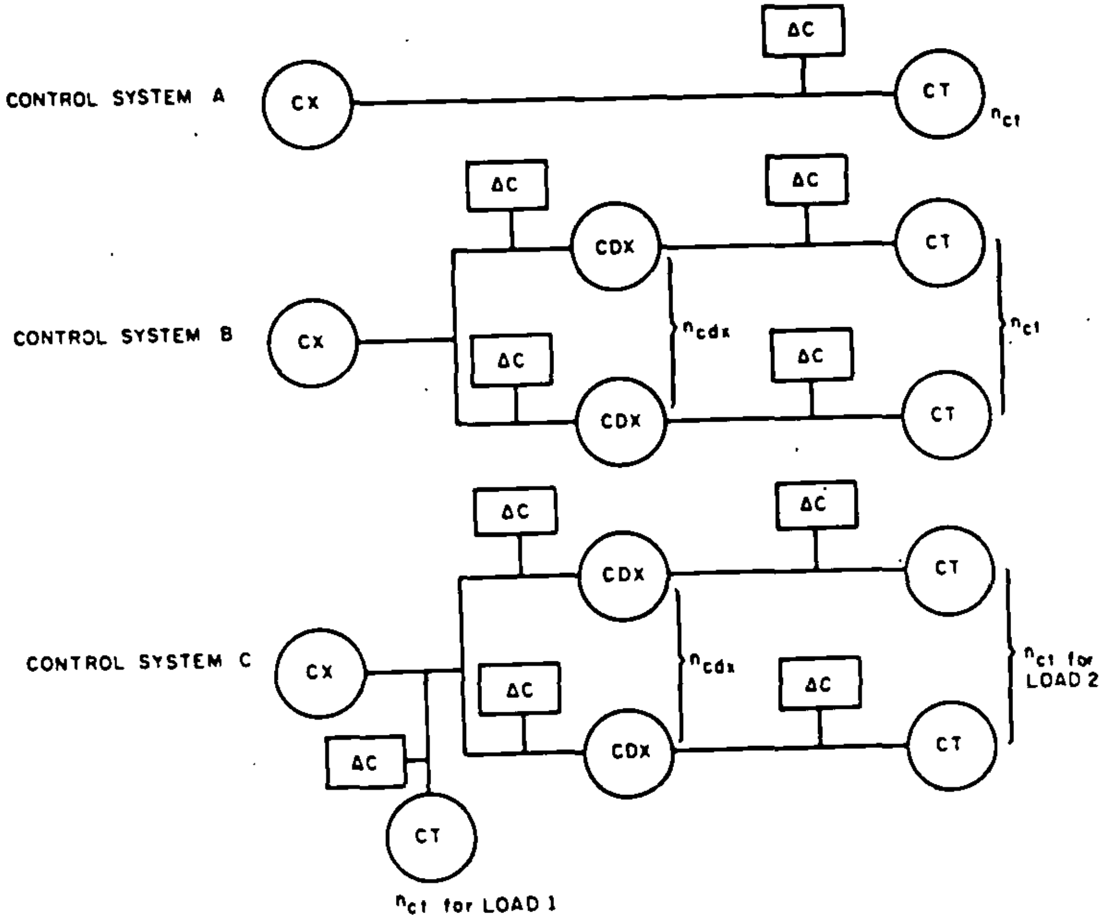


FIGURE 60. System designation key for control systems.

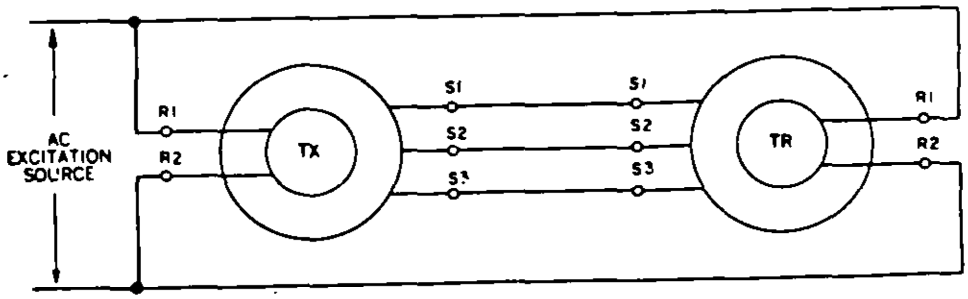


FIGURE 61. External connections of a transmitter-receiver system.

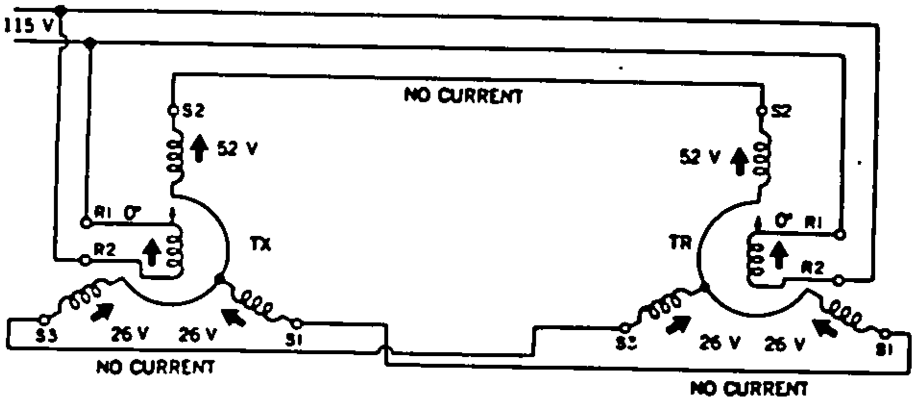


FIGURE 62. Internal conditions in TX-TR system with rotors in correspondence.

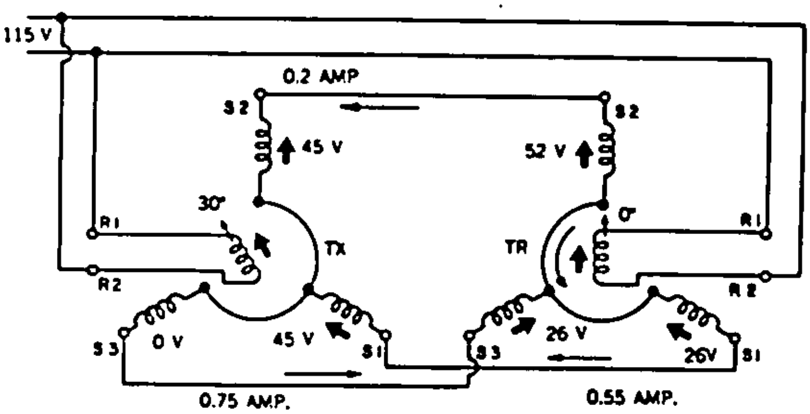


FIGURE 63. Internal conditions in TX-TR system with rotors not in correspondence.

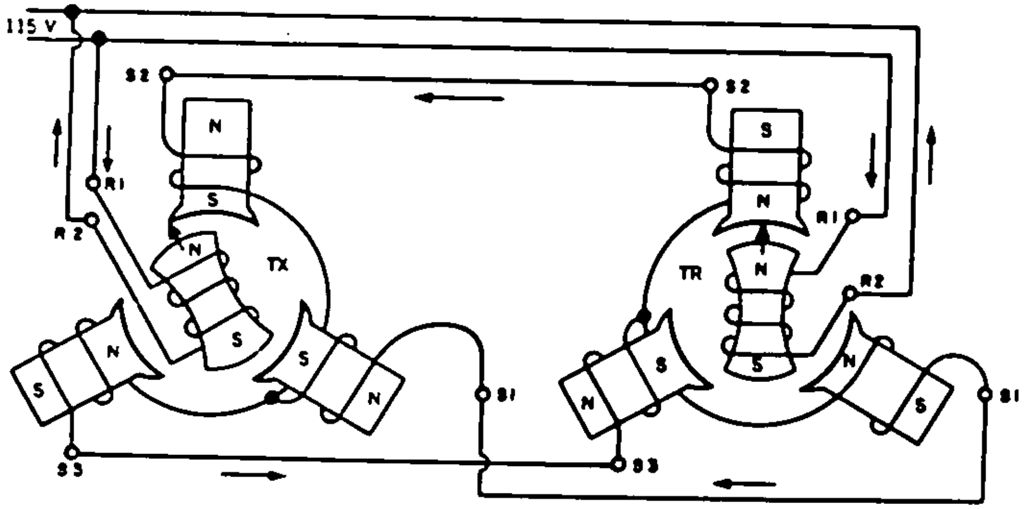


FIGURE 64. Magnetic polarities at a particular instant with TX rotor at 30° and TR rotor at 0°.

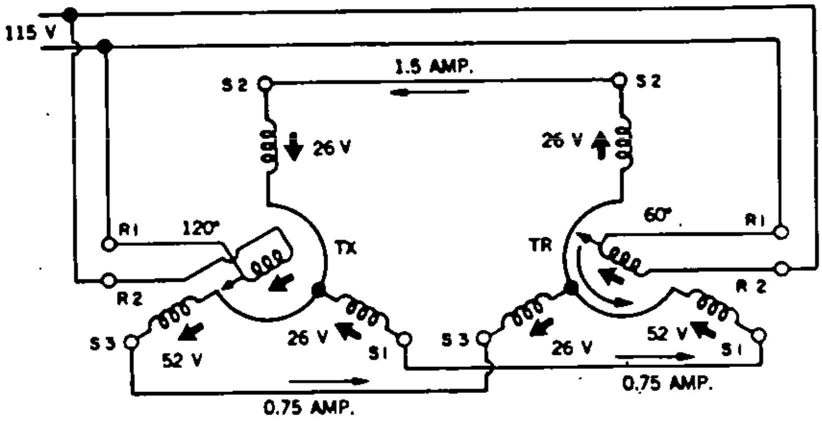


FIGURE 65. Internal conditions in TX-TR system with TX rotor at 120° and TR rotor at 60°.

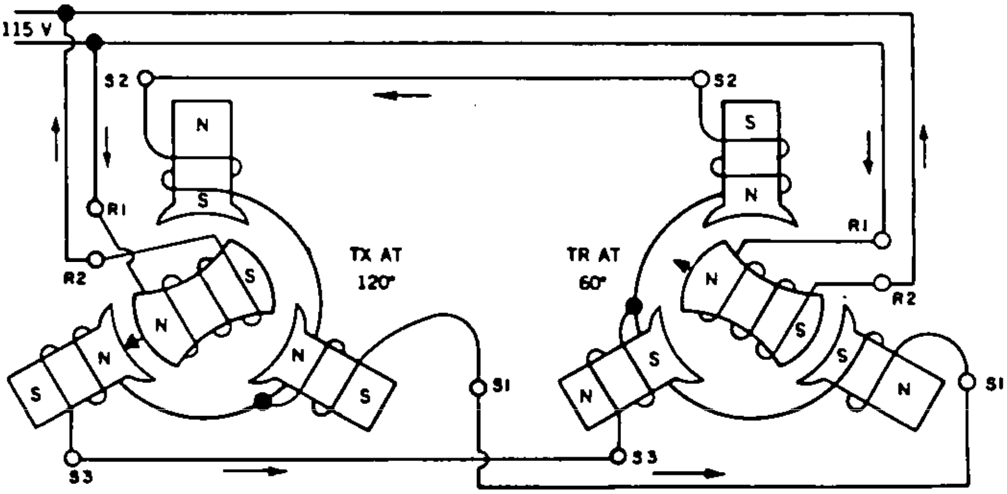


FIGURE 66. Magnetic polarities at a particular instant with TX rotor at 120° and TR rotor at 60°.

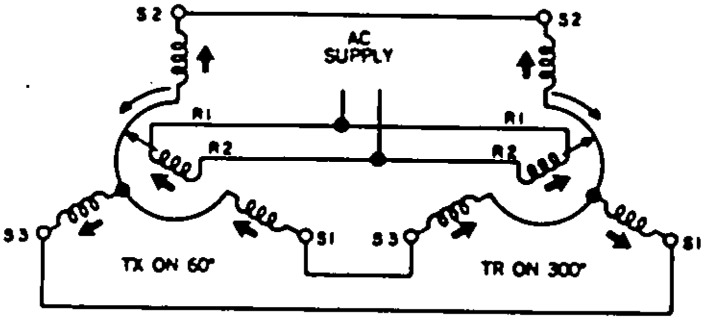


FIGURE 67. Effect of reversing S1 and S3 connections between TX and TR.

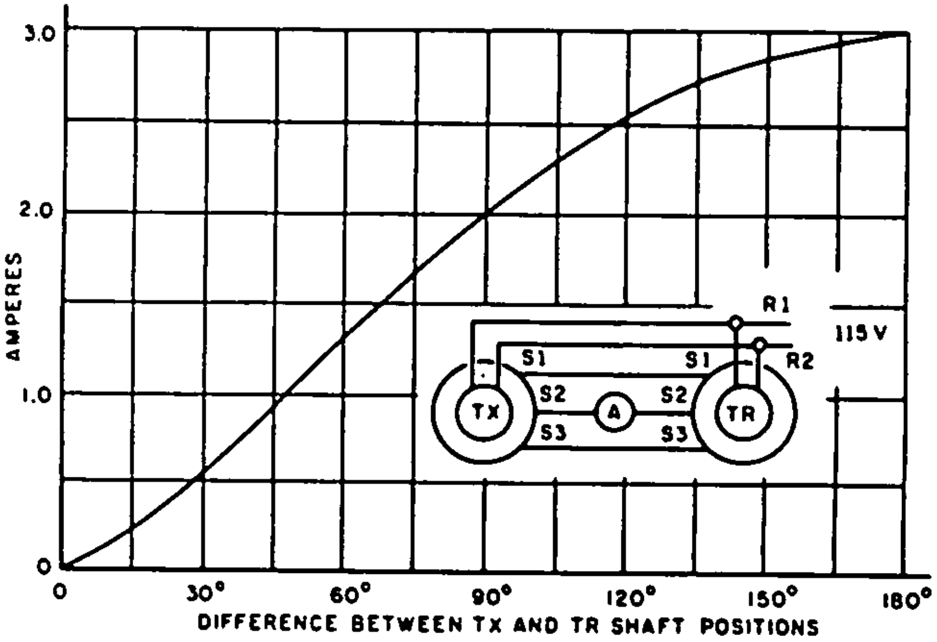
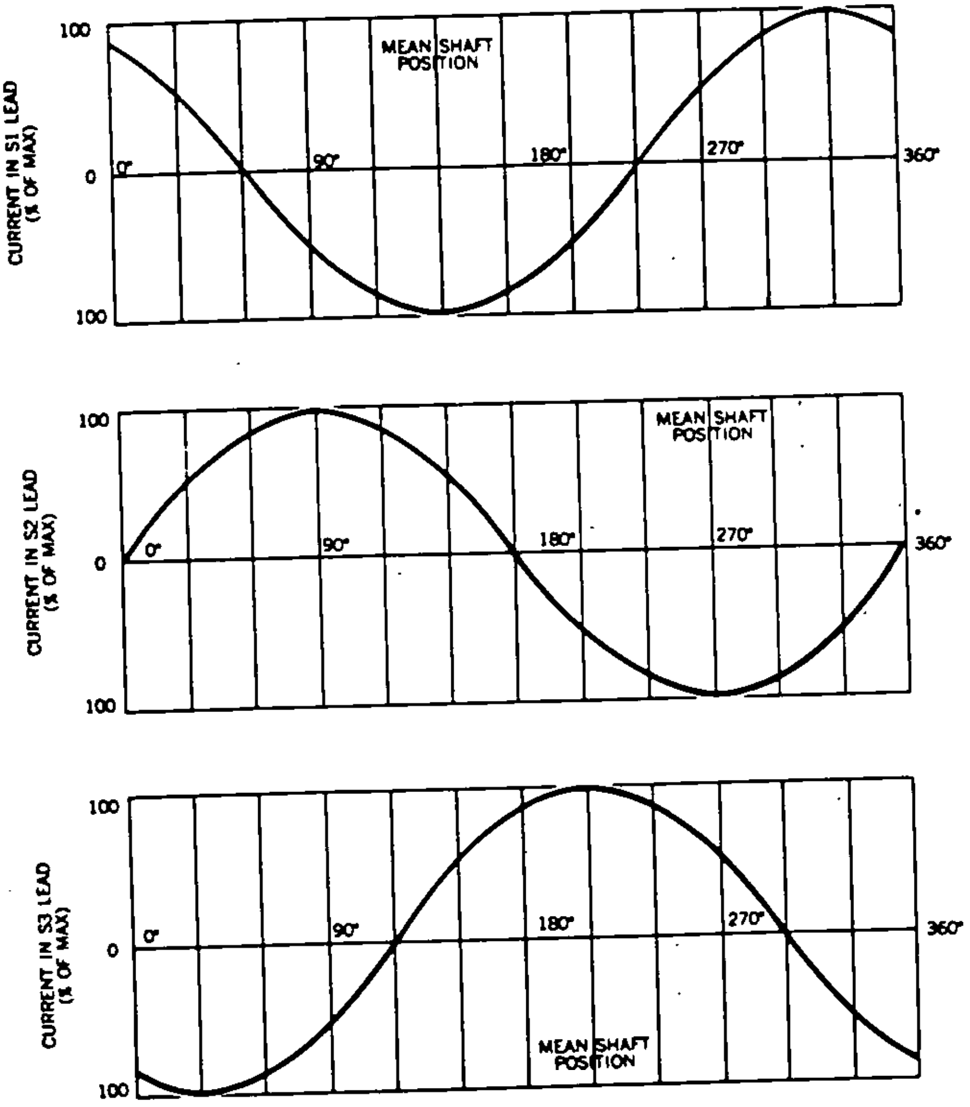


FIGURE 68. Effect of rotor position difference on maximum stator current.



NOTES:
ALL CURRENTS ARE RMS VALUE
CURRENTS SHOWN ABOVE THE 0 LINE ARE IN PHASE WITH S1 CURRENT AT 0°
CURRENTS SHOWN BELOW THE 0 LINE ARE 180° OUT OF PHASE WITH S1 CURRENT AT 0°

FIGURE 69. Effect of actual rotor position on individual stator current.

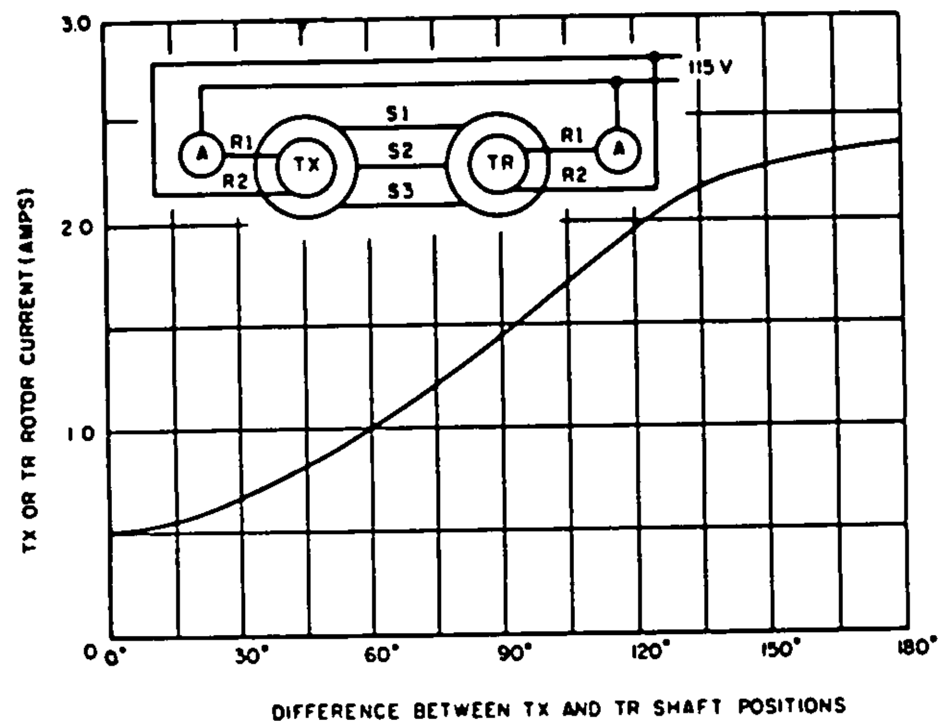


FIGURE 70. Effect of rotor position difference on rotor current.

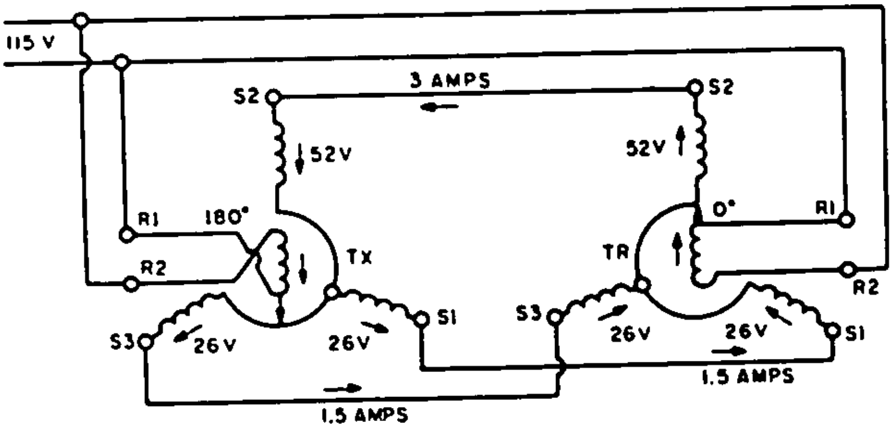


FIGURE 71. Internal conditions in TX-TR system when TX and TR rotors are 180° apart.

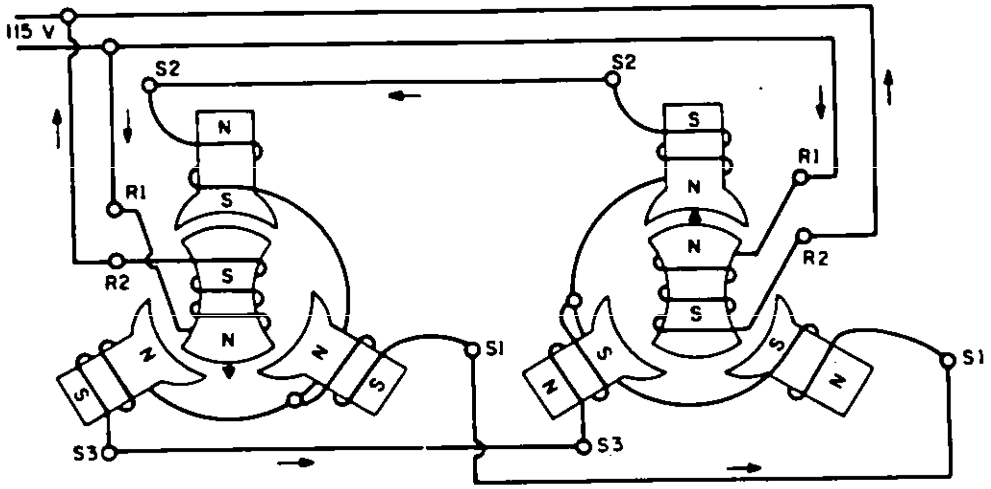


FIGURE 72. Magnetic polarities at a particular instant when TX and TR rotors are 180° apart.

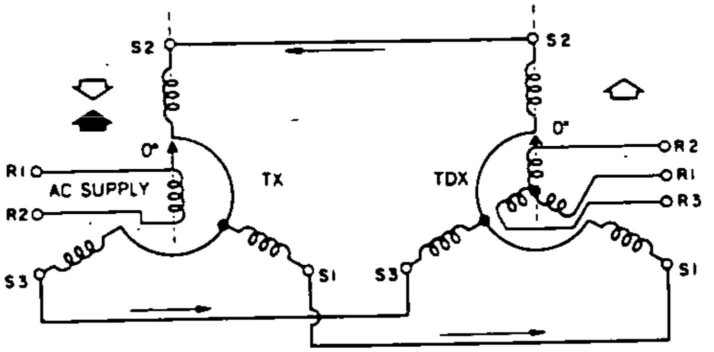


FIGURE 73. Position of TDX stator field when TX rotor is at 0°.

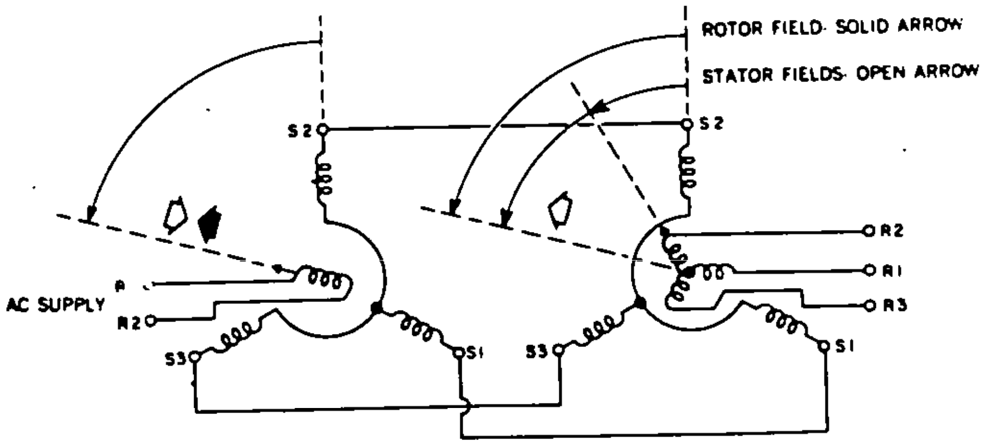


FIGURE 74. Rotating TDX stator field by turning the TX rotor.

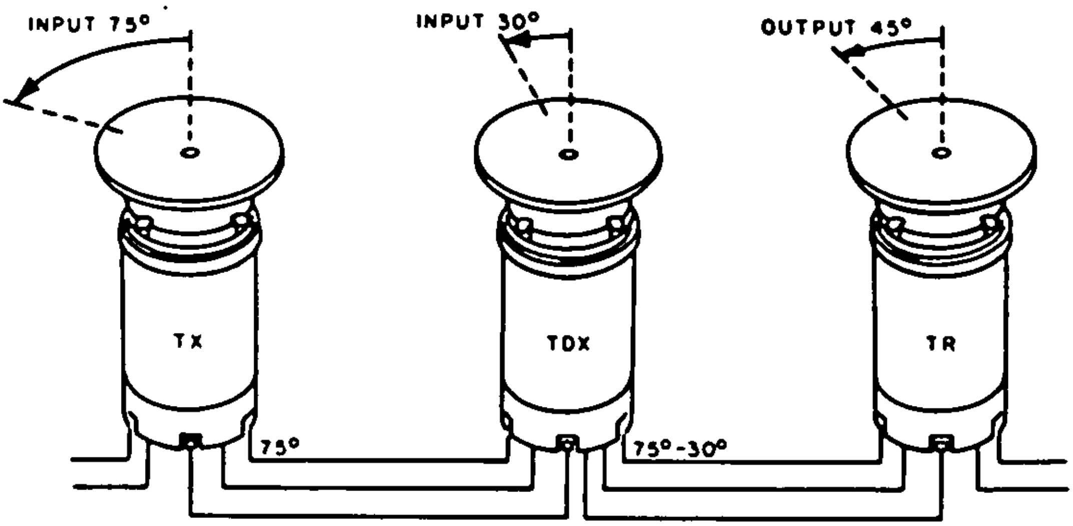


FIGURE 75. Subtraction with TDX.

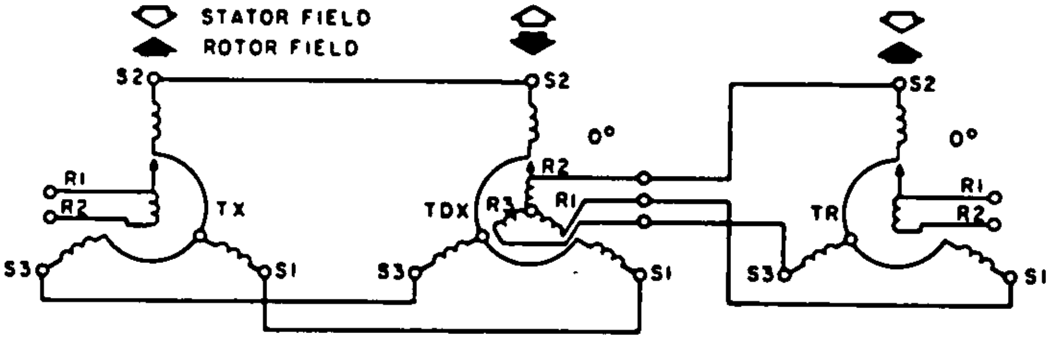


FIGURE 76. Magnetic field positions in TX-TDX-TR system with all rotors at 0°.

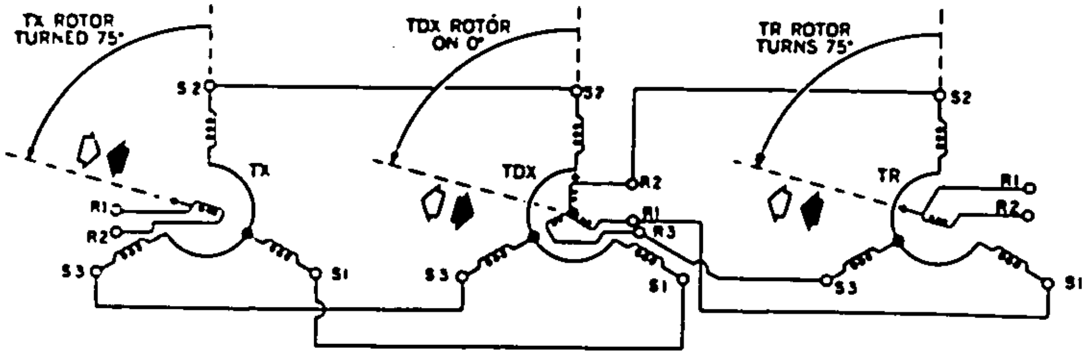


FIGURE 77. Effect of turning TX rotor in TX-TDX-TR system connected for subtraction.

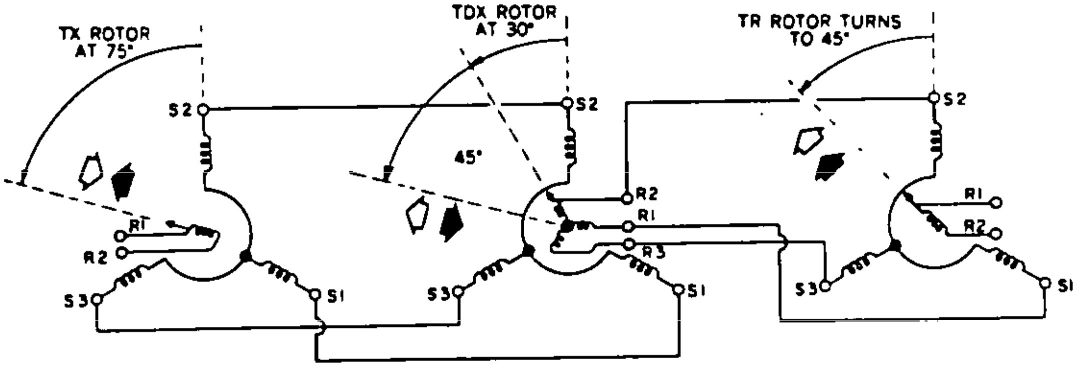


FIGURE 78. Effect of turning TDX rotor in TX-TDX-TR system connected for subtraction.

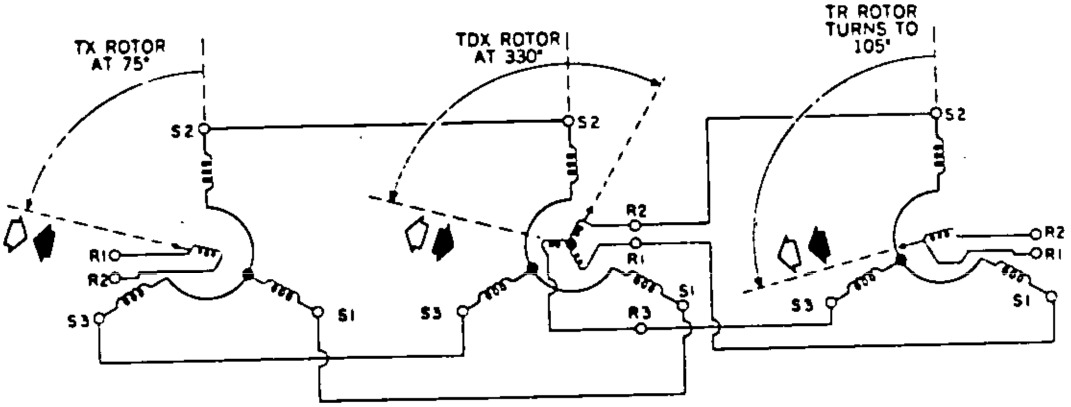


FIGURE 79. Effect of turning TDX rotor clockwise in a TX-TDX-TR system connected for subtraction.

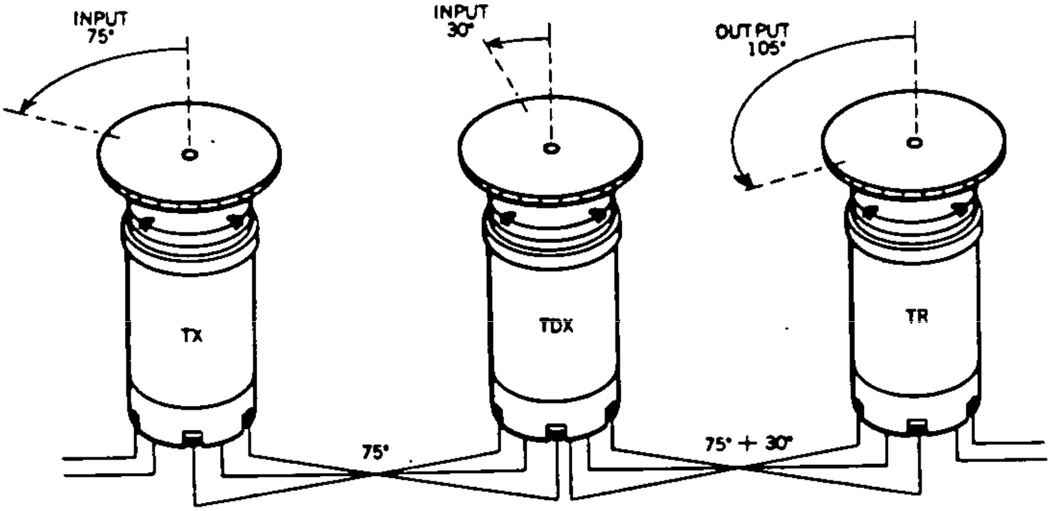


FIGURE 80. Addition with TDX.

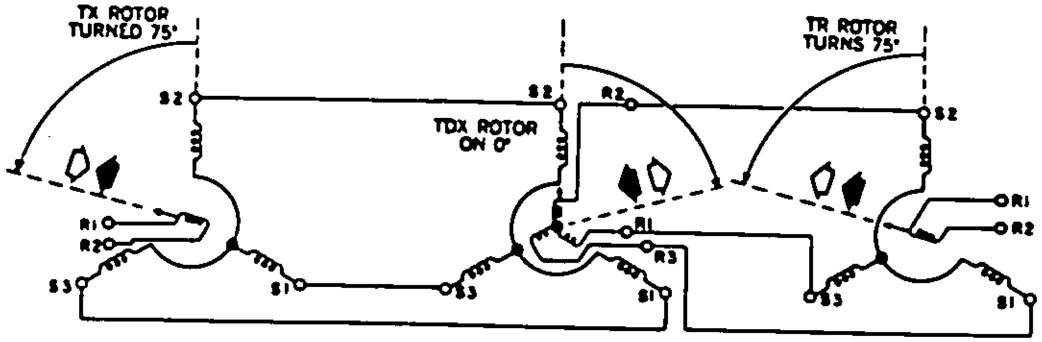


FIGURE 81. Effect of turning TX rotor in TX-TDX-TR system connected for addition.

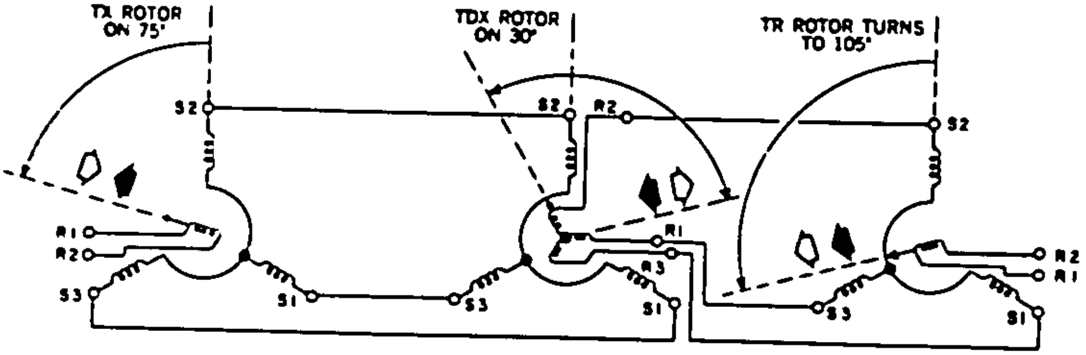


FIGURE 82. Effect of turning TDX rotor in TX-TDX-TR system connected for addition.

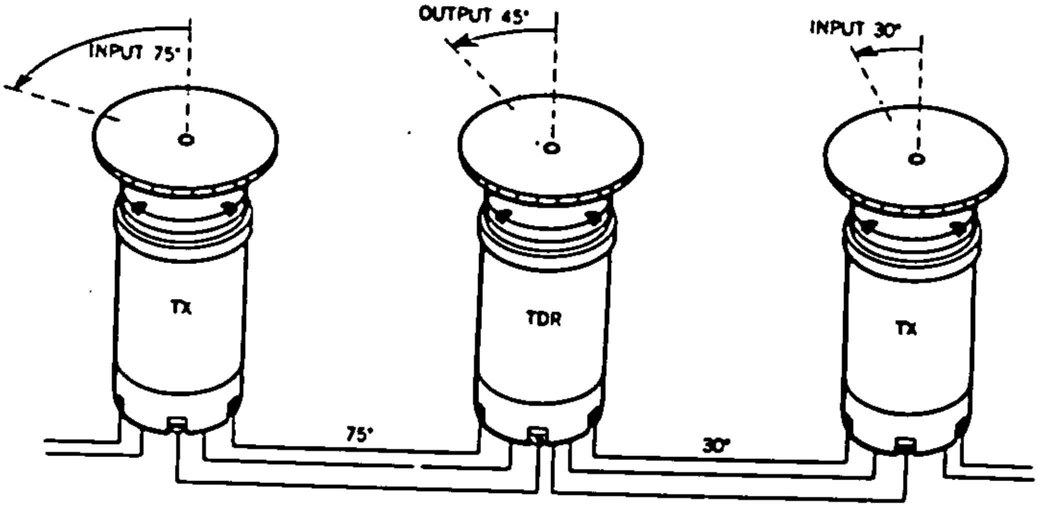


FIGURE 83. Subtraction with TDR.

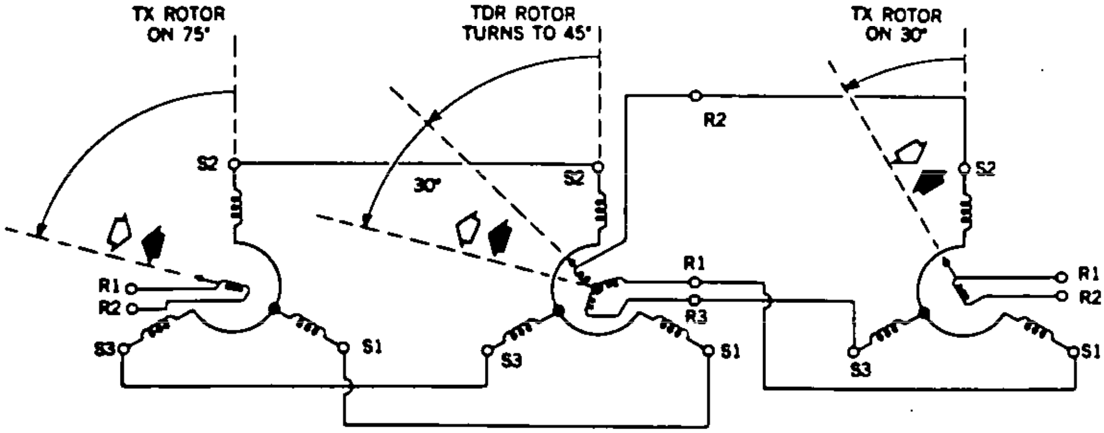


FIGURE 84. Effect of turning both TX rotors in TX-TDR-TX system connected for subtraction.

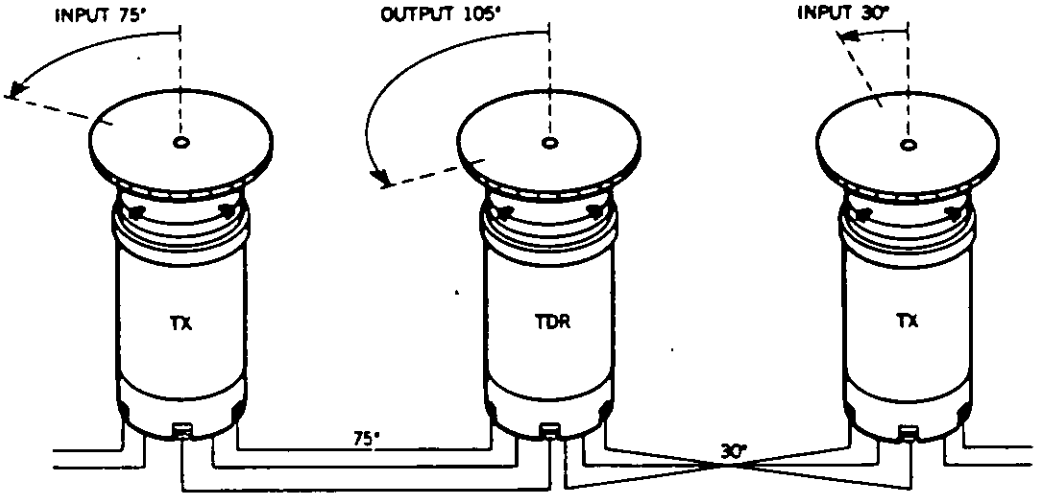


FIGURE 85. Addition with TDR.

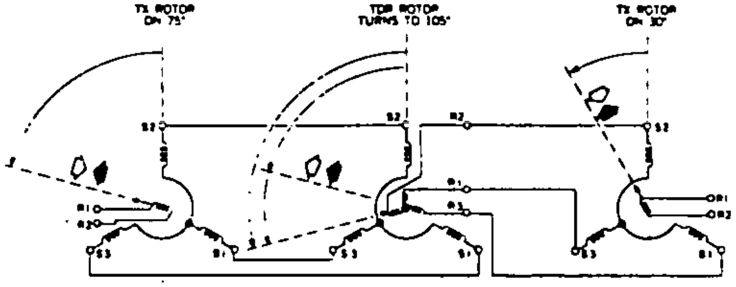


FIGURE 86. Effect of turning both TX rotors in TX-TDR-TX system connected for addition.

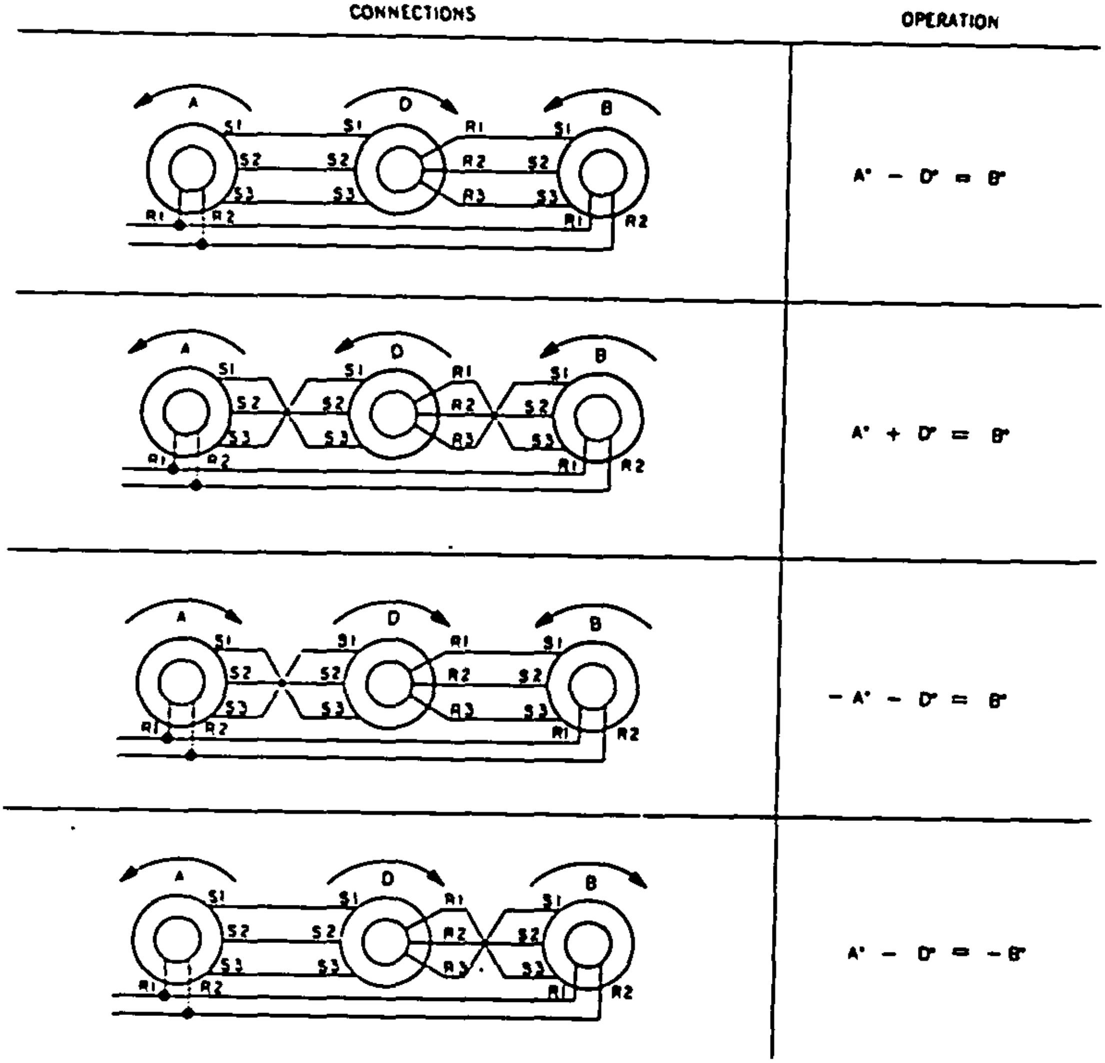


FIGURE 87. Standard connections for differentials.

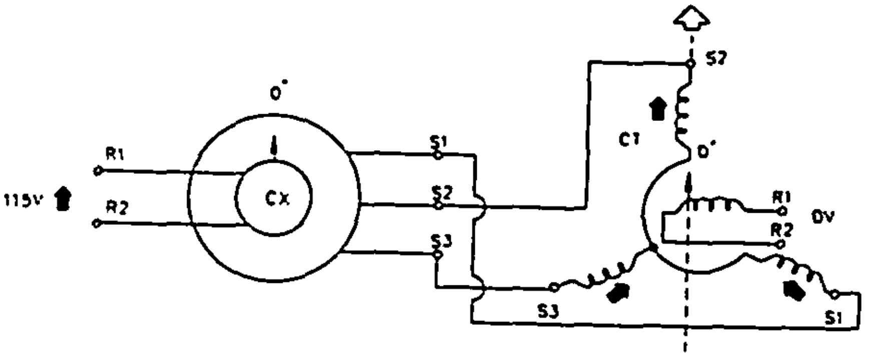


FIGURE 88. Conditions in CX-CT system with rotors in correspondence.

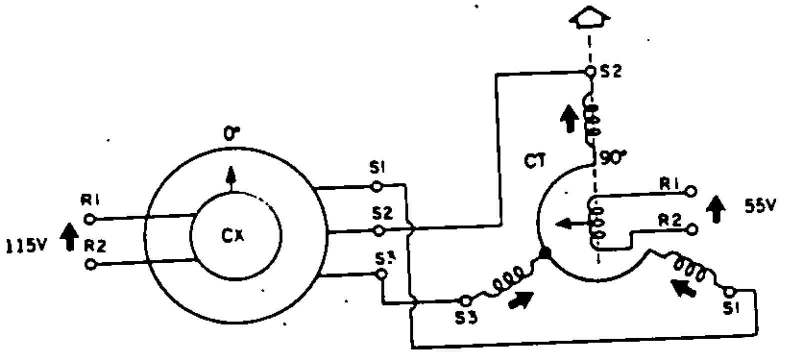


FIGURE 89. Conditions in CX-CT system with CX rotor at 0° and CT rotor at 90°.

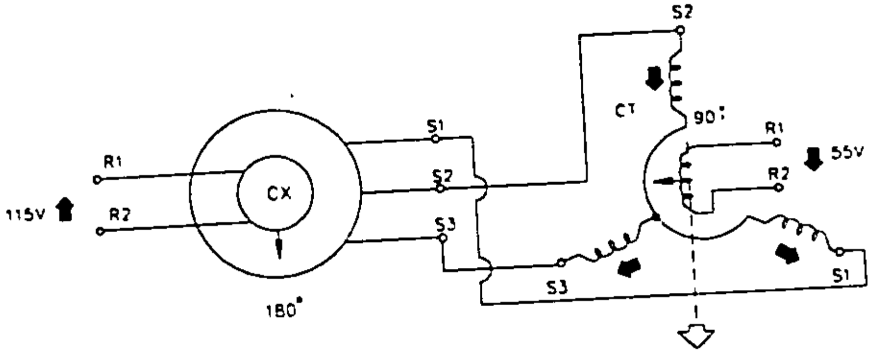


FIGURE 90. Conditions in CX-CT system with CX rotor at 180° and CT rotor at 90°.

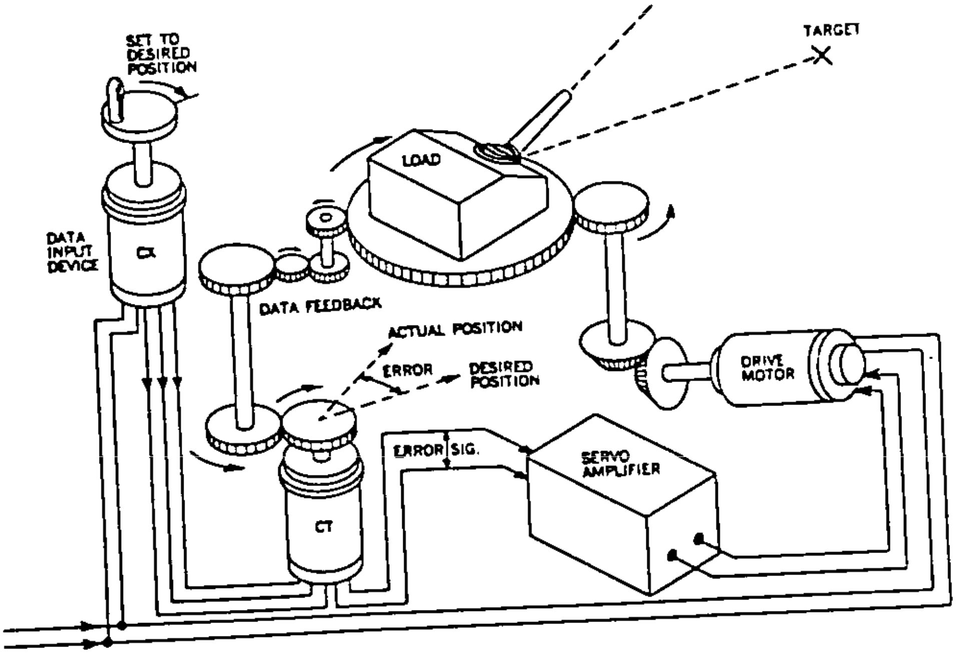
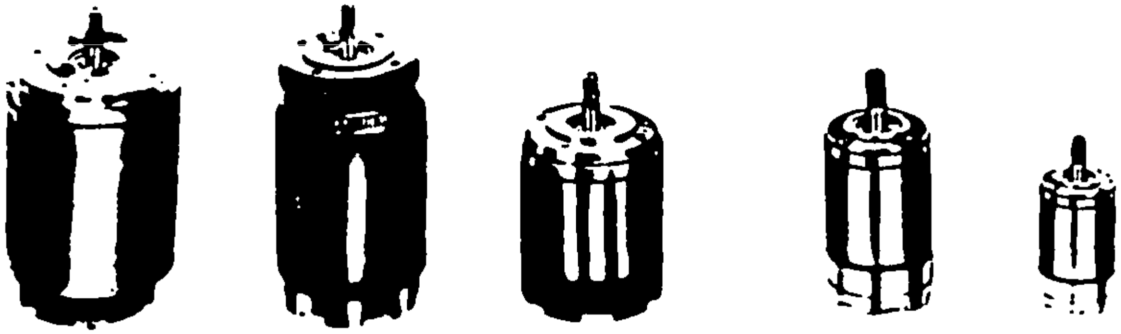
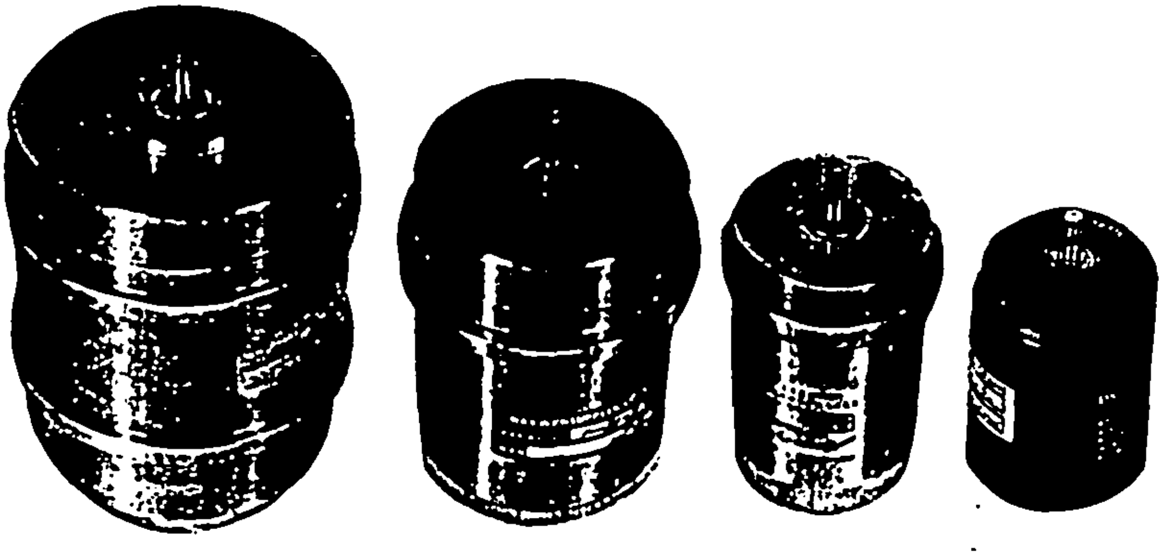


FIGURE 91. Typical position servo.

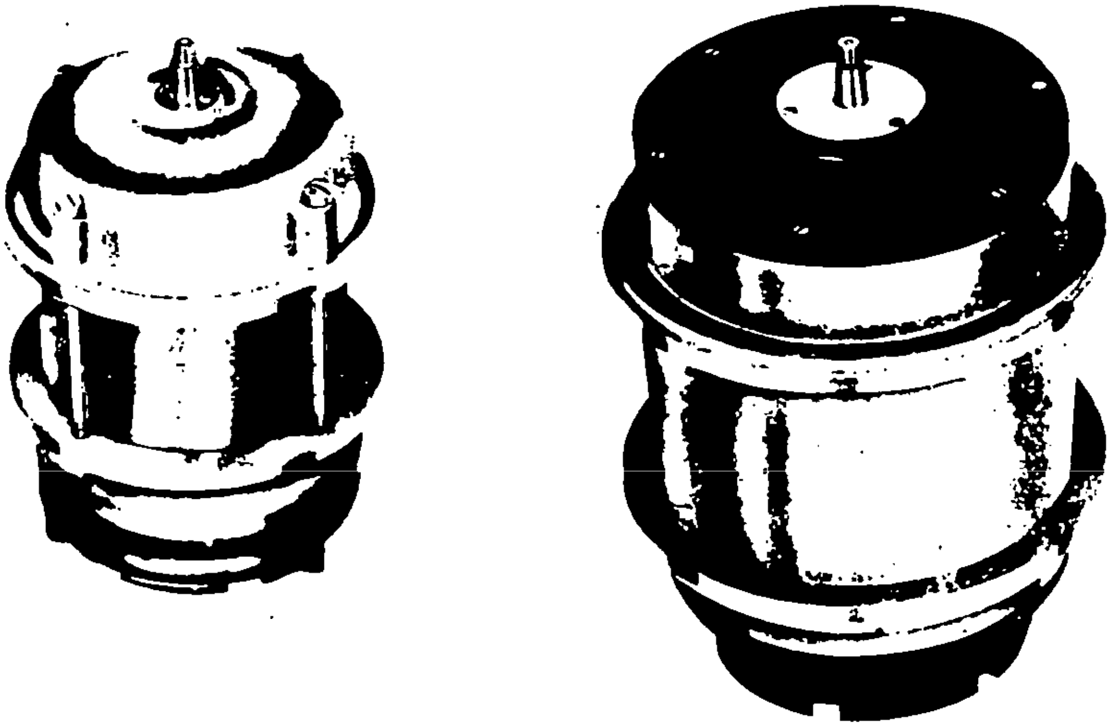


Size 18 Size 16 Size 15 Size 11 Size 08



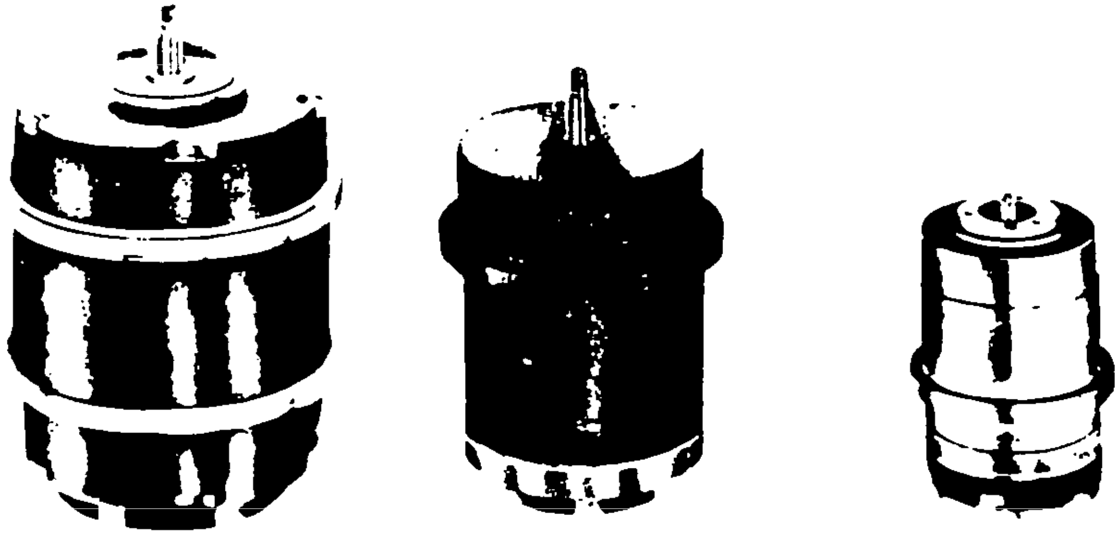
Size 37 Size 31 Size 23 Size 19

FIGURE 92. Standard synchro sizes; approximately one-half actual size.



Size 6

Size 7



Size 5

Size 3

Size 1

FIGURE 93. Pre-standard synchro sizes; approximately one-half actual size.

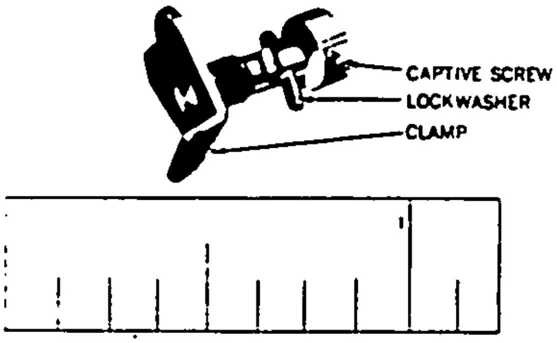


FIGURE 94. Mounting clamp assembly - MS17183 (or equal).

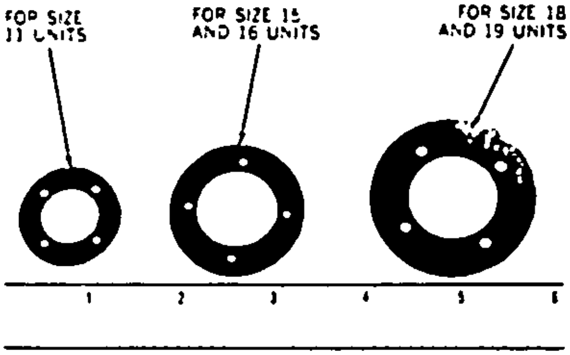


FIGURE 95. Clamping discs - MS90400.

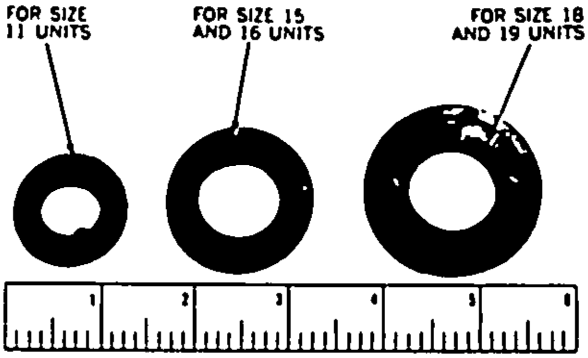
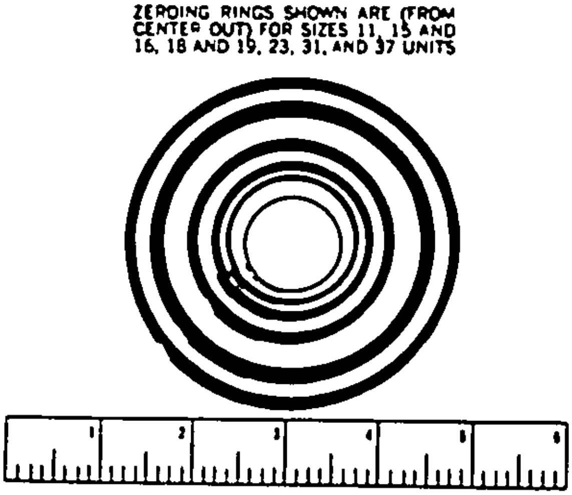


FIGURE 96. Adapter assemblies - MS90401.



ZEROING RINGS SHOWN ARE (FROM CENTER OUT) FOR SIZES 11, 15 AND 16, 18 AND 19, 23, 31, AND 37 UNITS

FIGURE 97. Zeroing rings - MS90398.

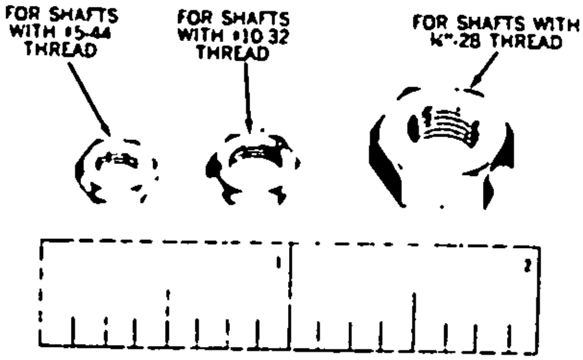

FOR SHAFTS WITH #5-44 THREAD
FOR SHAFTS WITH #10 32 THREAD
FOR SHAFTS WITH ¼"-28 THREAD
1
2

FIGURE 98. Shaft nuts - MS17187.

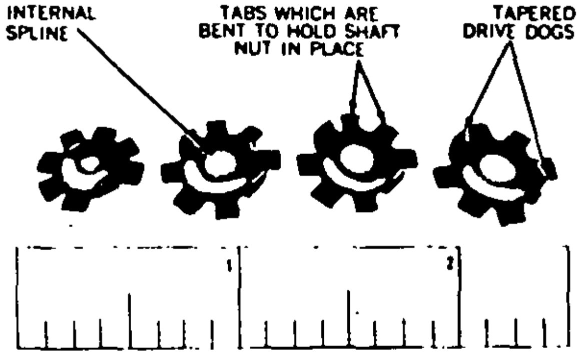
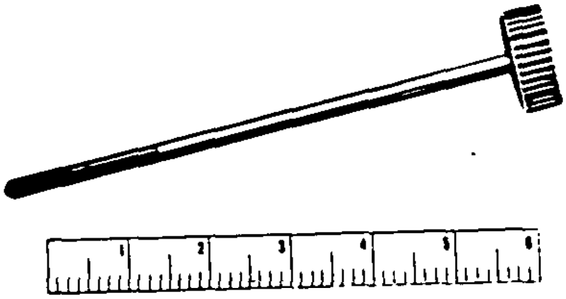

INTERNAL SPLINE
TABS WHICH ARE BENT TO HOLD SHAFT NUT IN PLACE
TAPERED DRIVE DOGS
1
2

FIGURE 99. Drive washers - MS17186.



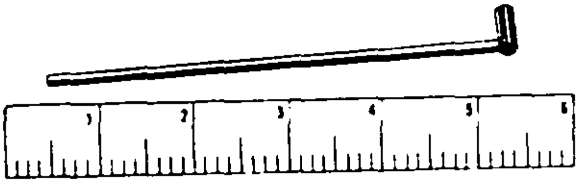


FIGURE 100. Straight pinion wrench - MS90393.

FIGURE 101. 90-degree pinion wrench - MS90394.

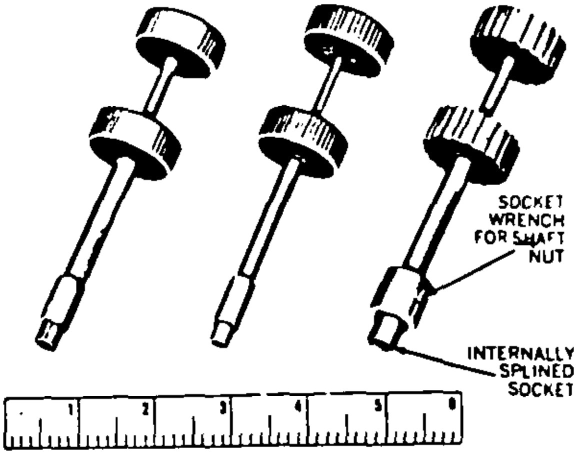


FIGURE 102. Socket wrench assemblies - MS90395.

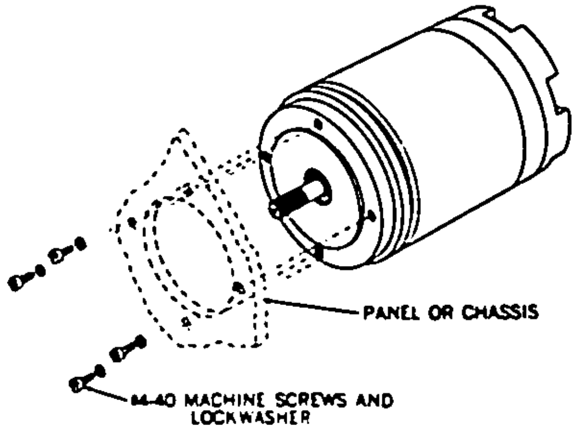


FIGURE 103. Mounting a synchro using a machine screw.

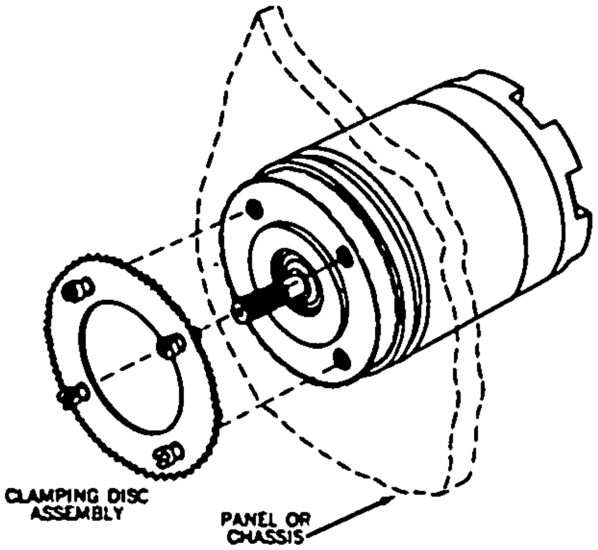


FIGURE 104. Mounting a synchro using a clamping disc assembly.

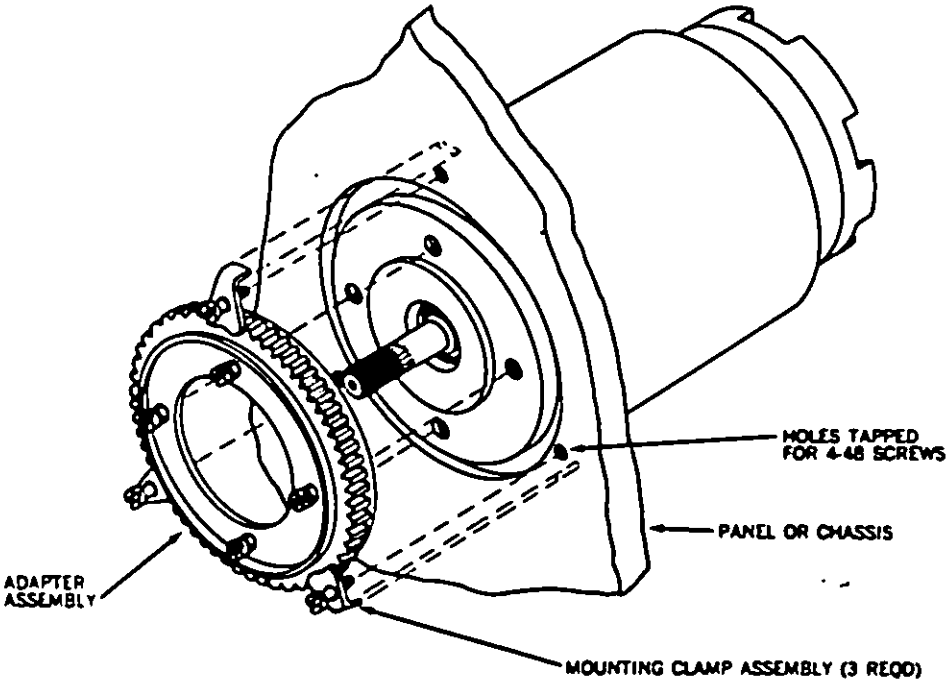

HOLES TAPPED FOR 4-40 SCREWS
PANEL OR CHASSIS
ADAPTER ASSEMBLY
MOUNTING CLAMP ASSEMBLY (3 REQD)

FIGURE 105. Mounting a synchro using an adapter assembly (from the shaft end).

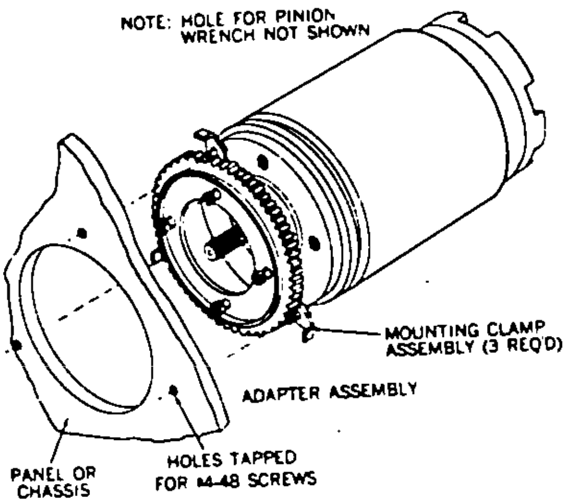

NOTE: HOLE FOR PINION WRENCH NOT SHOWN
MOUNTING CLAMP ASSEMBLY (3 REQ'D)
ADAPTER ASSEMBLY
PANEL OR CHASSIS
HOLES TAPPED FOR #4-48 SCREWS

FIGURE 106. Mounting a synchro using an adapter assembly (from the terminal board end).

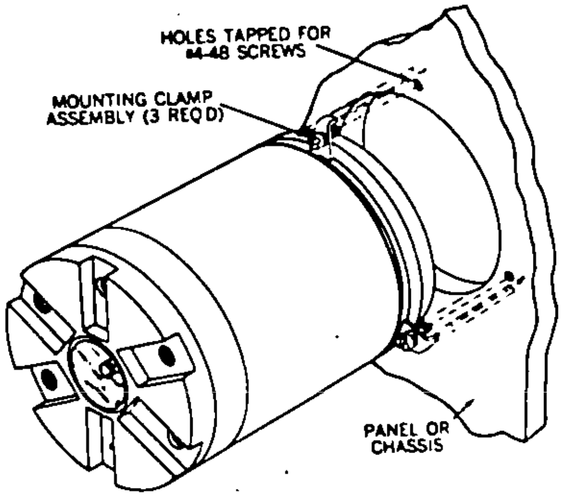

HOLES TAPPED FOR #4-48 SCREWS
MOUNTING CLAMP ASSEMBLY (3 REQ'D)
PANEL OR CHASSIS

FIGURE 107. Mounting a synchro using three mounting clamp assemblies.

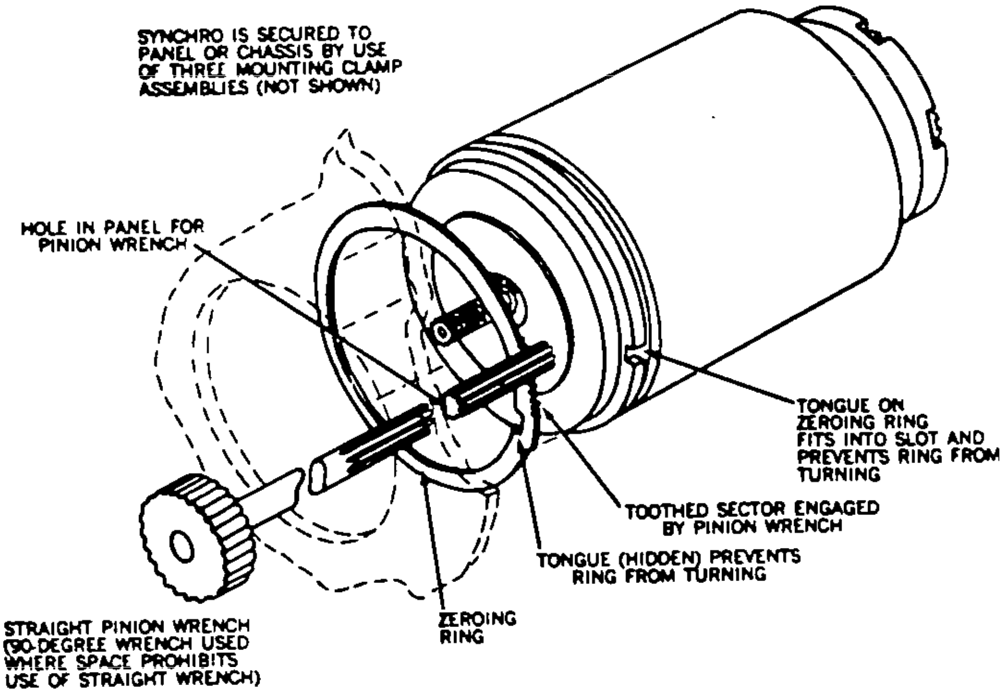

SYNCHRO IS SECURED TO PANEL OR CHASSIS BY USE OF THREE MOUNTING CLAMP ASSEMBLIES (NOT SHOWN)
HOLE IN PANEL FOR PINION WRENCH
TONGUE ON ZEROING RING FITS INTO SLOT AND PREVENTS RING FROM TURNING
TOOTHED SECTOR ENGAGED BY PINION WRENCH
TONGUE (HIDDEN) PREVENTS RING FROM TURNING
ZEROING RING
STRAIGHT PINION WRENCH (90-DEGREE WRENCH USED WHERE SPACE PROHIBITS USE OF STRAIGHT WRENCH)

FIGURE 108. Mounting a synchro using a zeroing ring.

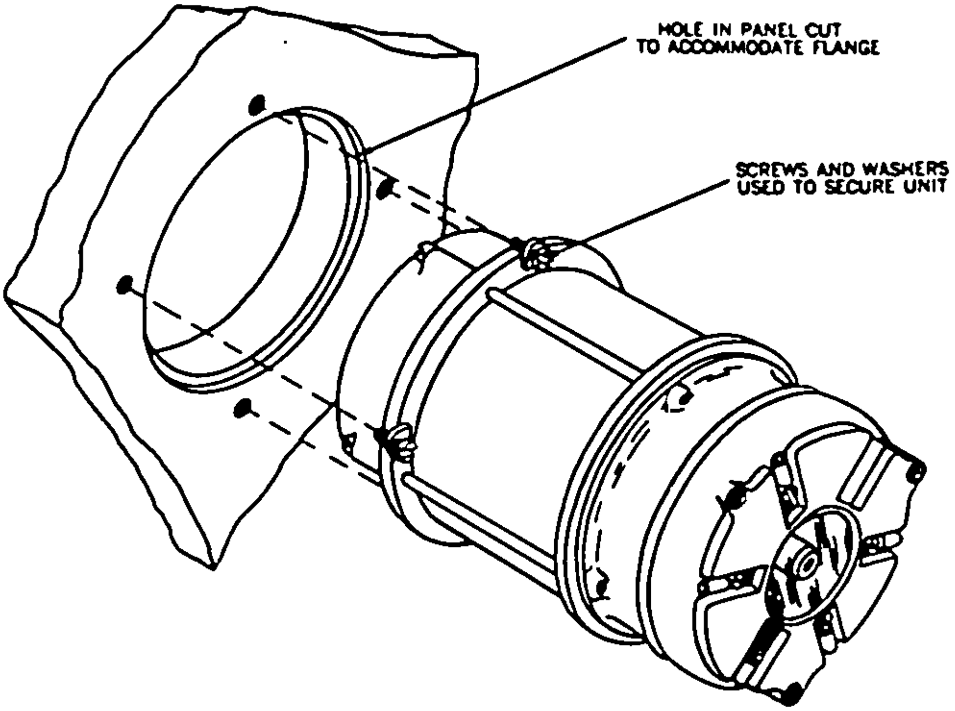


FIGURE 109. Flange-mounted synchro.

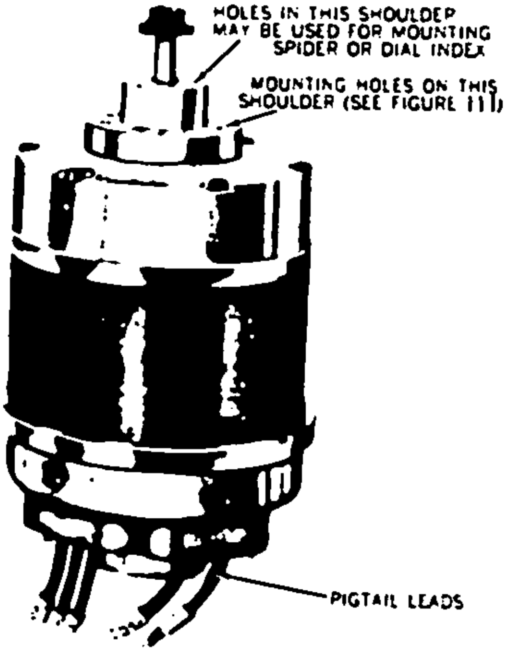


FIGURE 110. Type 5N nozzle-mounted synchro.

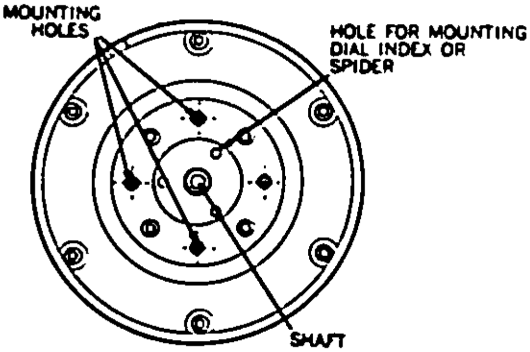


FIGURE 111. End view of nozzle-mounted synchro.

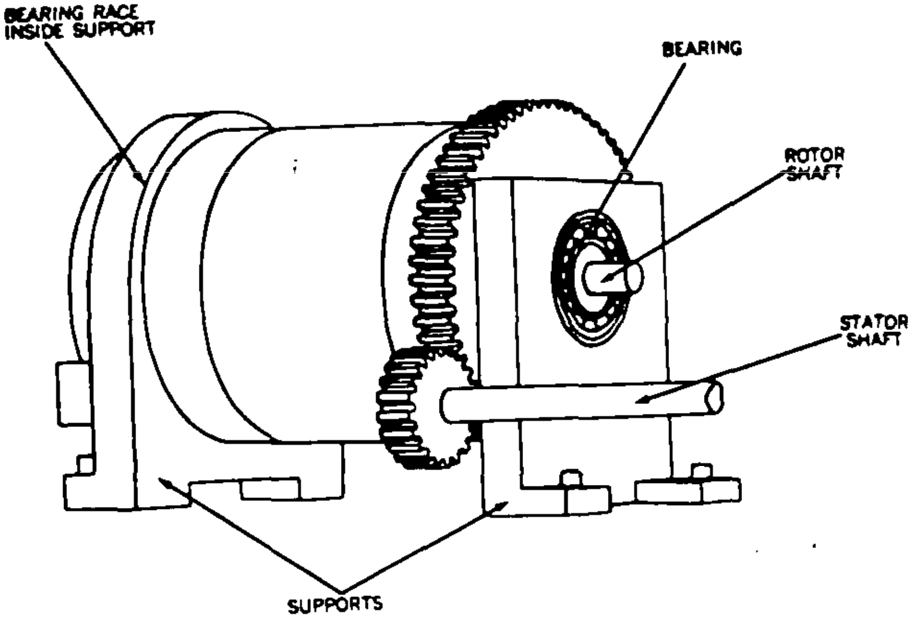


FIGURE 112. Bearing-mounted synchro.

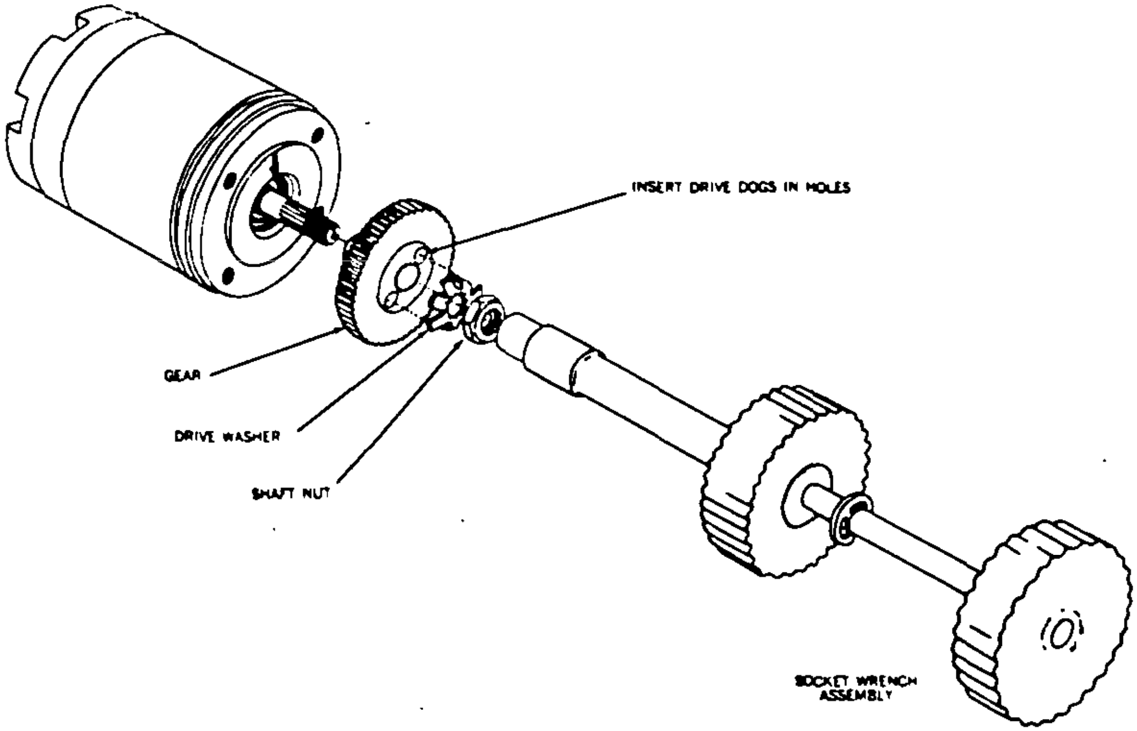


FIGURE 113. Mounting a gear on a standard synchro (exploded view).

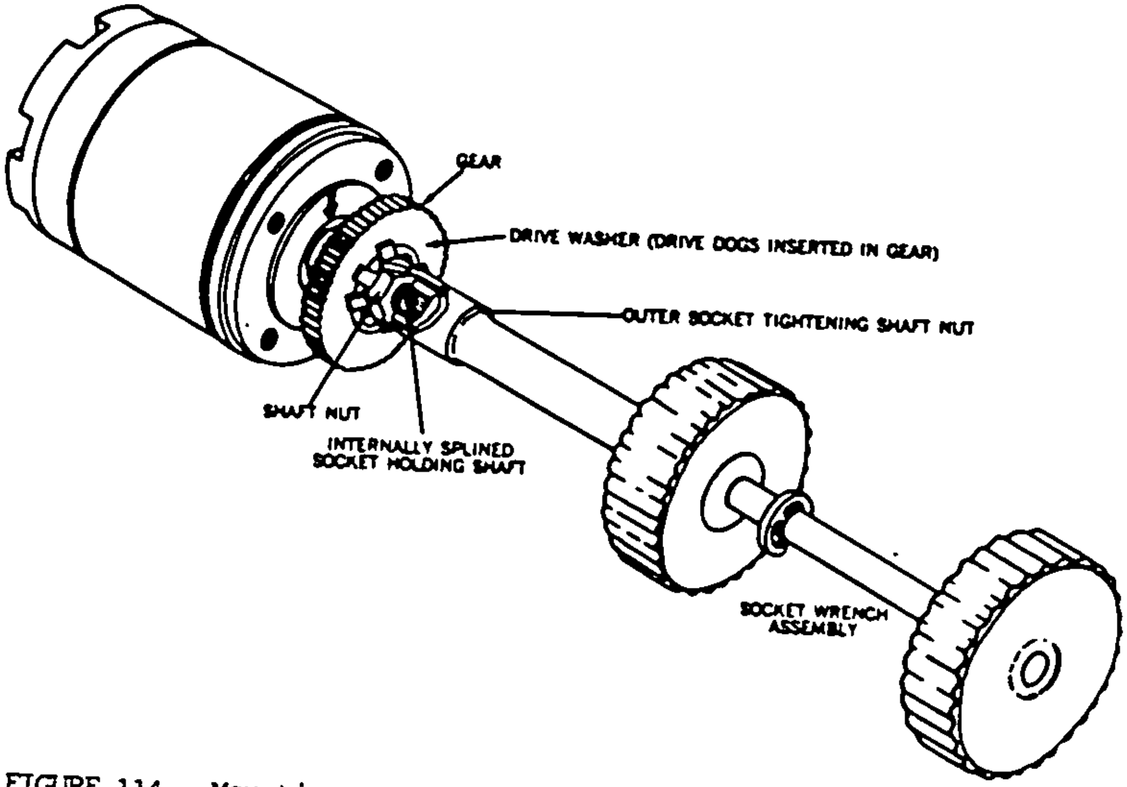
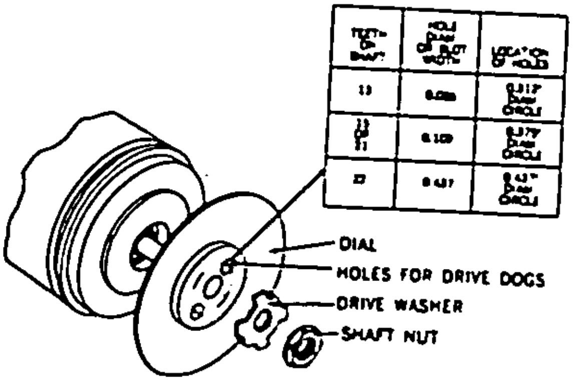

GEAR
DRIVE WASHER (DRIVE DOGS INSERTED IN GEAR)
OUTER SOCKET TIGHTENING SHAFT NUT
SHAFT NUT
INTERNALLY SPLINED SOCKET HOLDING SHAFT
SOCKET WRENCH ASSEMBLY

FIGURE 114. Mounting a gear on a standard synchro (assembled cutaway view).



HOLE SIZE AND LOCATION DATA ALSO APPLIES TO GEARS

FIGURE 115. Mounting a dial on a standard synchro.

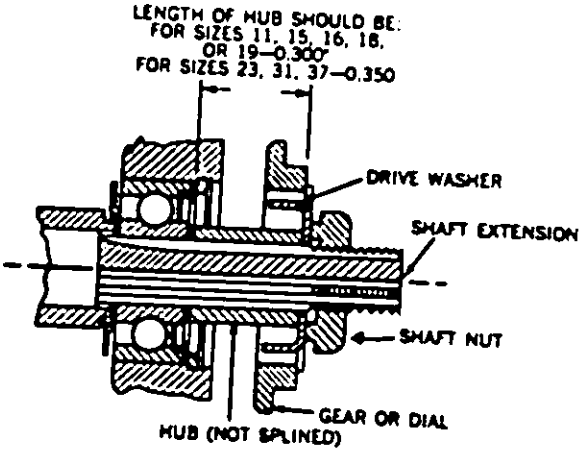


FIGURE 116. Correct positioning of drive washer to insure maximum loading (cross section).

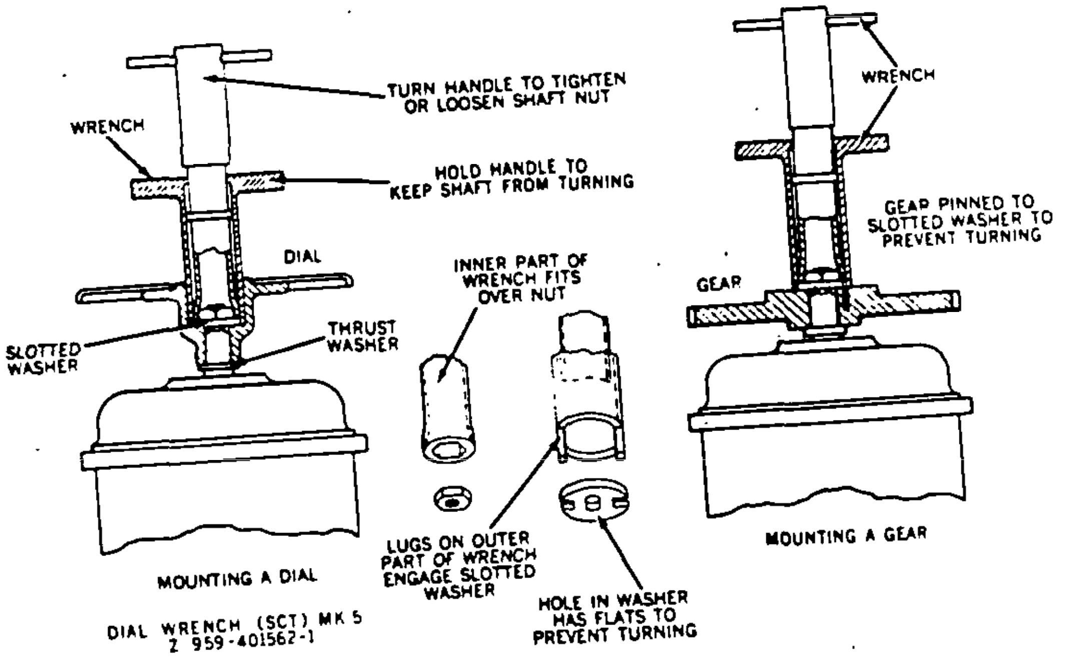

WRENCH
TURN HANDLE TO TIGHTEN OR LOOSEN SHAFT NUT
HOLD HANDLE TO KEEP SHAFT FROM TURNING
DIAL
SLOTTED WASHER
THRUST WASHER
INNER PART OF WRENCH FITS OVER NUT
LUGS ON OUTER PART OF WRENCH ENGAGE SLOTTED WASHER
HOLE IN WASHER HAS FLATS TO PREVENT TURNING
MOUNTING A DIAL
DIAL WRENCH (SCT) MK 5
Z 959-401562-1
WRENCH
GEAR PINNED TO SLOTTED WASHER TO PREVENT TURNING
GEAR
MOUNTING A GEAR

FIGURE 117. Mounting gears or dials on pre-standard synchros.

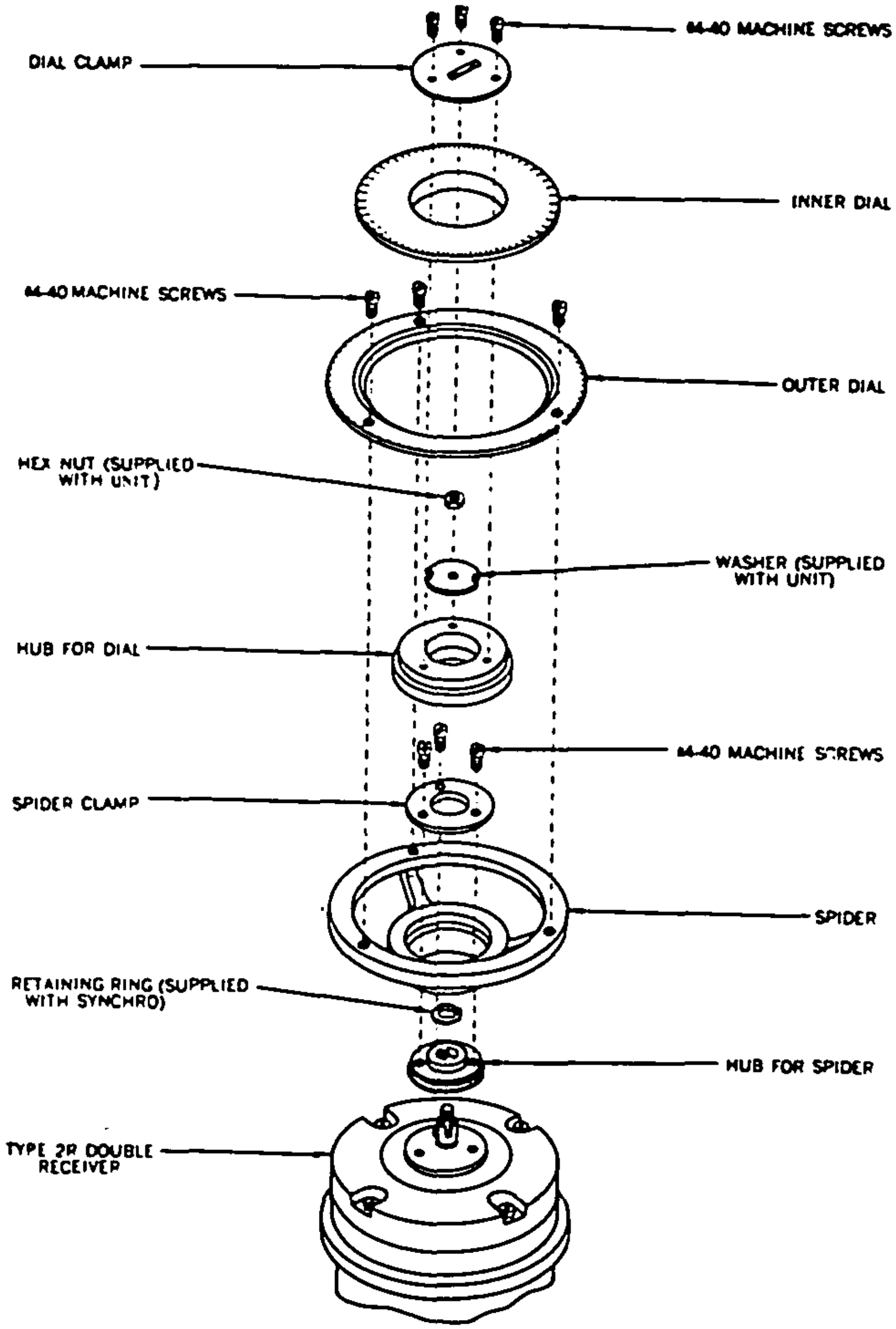
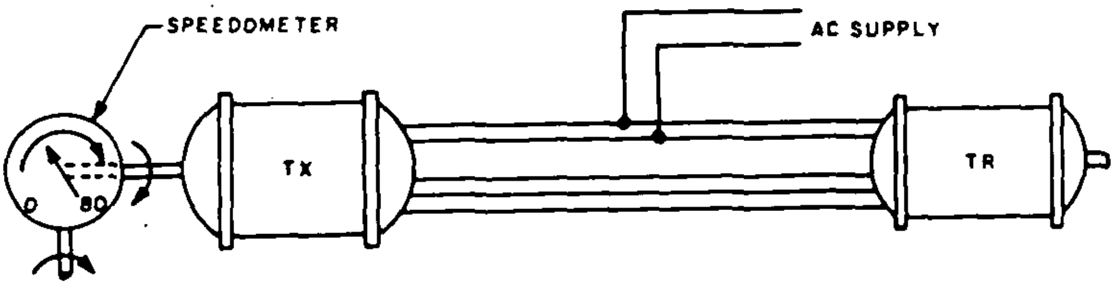


FIGURE 118. Mounting dials on a 2R double receiver.



WHEN CAR GOES FASTER, TRANSMITTER TRANSMITS AN INCREASING READING TO RECEIVER

FIGURE 119. Example of an increasing reading.

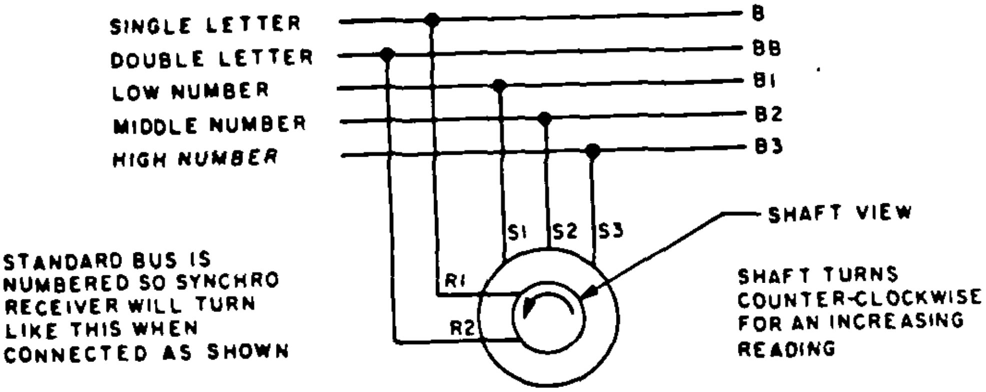

SINGLE LETTER
DOUBLE LETTER
LOW NUMBER
MIDDLE NUMBER
HIGH NUMBER
B
BB
B1
B2
B3
S1
S2
S3
R1
R2
SHAFT VIEW
STANDARD BUS IS NUMBERED SO SYNCHRO RECEIVER WILL TURN LIKE THIS WHEN CONNECTED AS SHOWN
SHAFT TURNS COUNTER-CLOCKWISE FOR AN INCREASING READING

FIGURE 120. Standard wire designations.

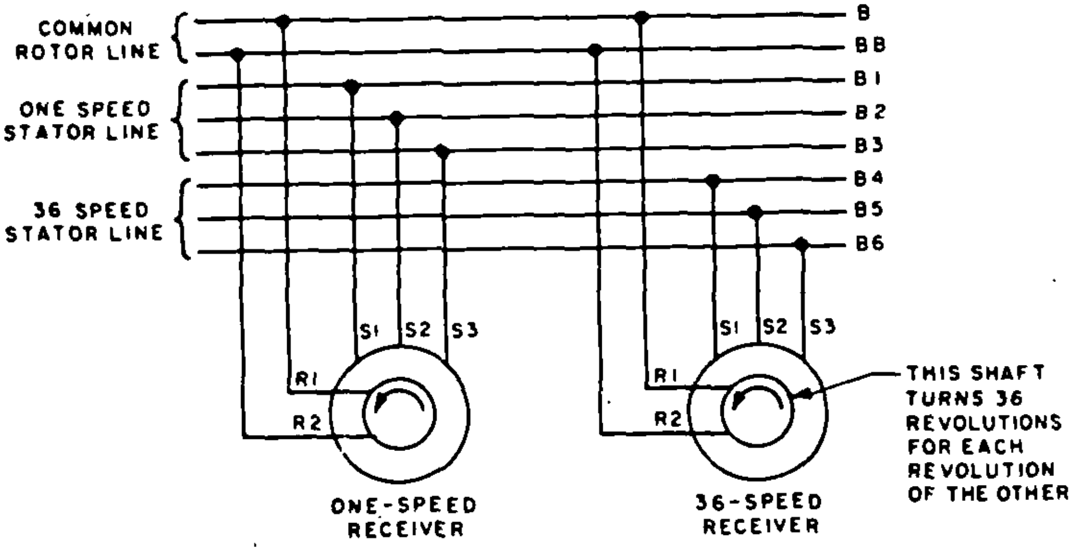
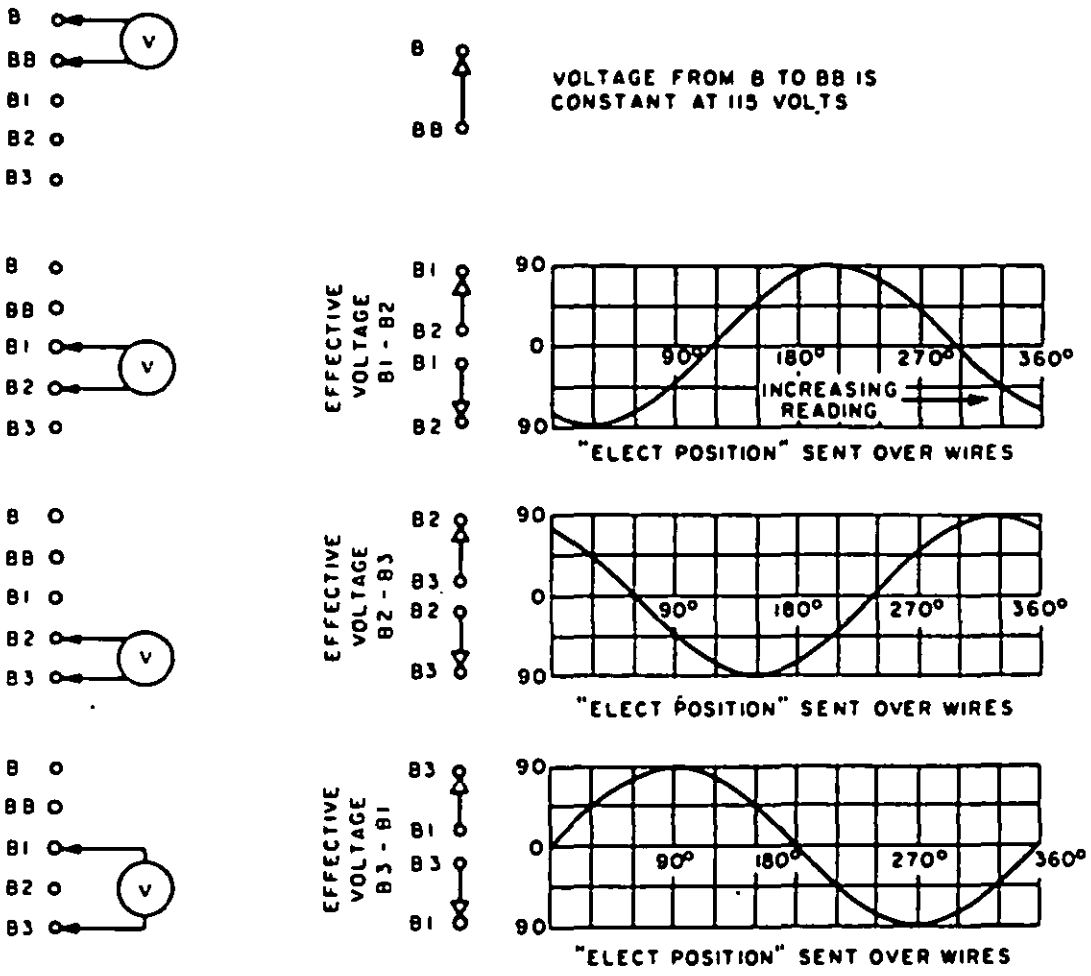


FIGURE 121. Connections on a typical two-speed system.


B
BB
B1
B2
B3
V
VOLTAGE FROM B TO BB IS CONSTANT AT 115 VOLTS
EFFECTIVE VOLTAGE B1 - B2
90
0
90
90°
180°
270°
360°
INCREASING READING
"ELECT POSITION" SENT OVER WIRES
EFFECTIVE VOLTAGE B2 - B3
EFFECTIVE VOLTAGE B3 - B1

NOTE: ALL VOLTAGES ARE 60 CYCLES AC EFFECTIVE VALUE
↑ INDICATES THAT VOLTAGE IS IN PHASE WITH B-BB
↓ INDICATES THAT VOLTAGE IS 180° OUT WITH B-BB

FIGURE 122. Standard voltages.

The actual numbers and letters used on a particular system may not agree with those used here. In any case, B represents the single-lettered bus, BB the double-lettered bus, B1 the low-numbered bus, and so on.

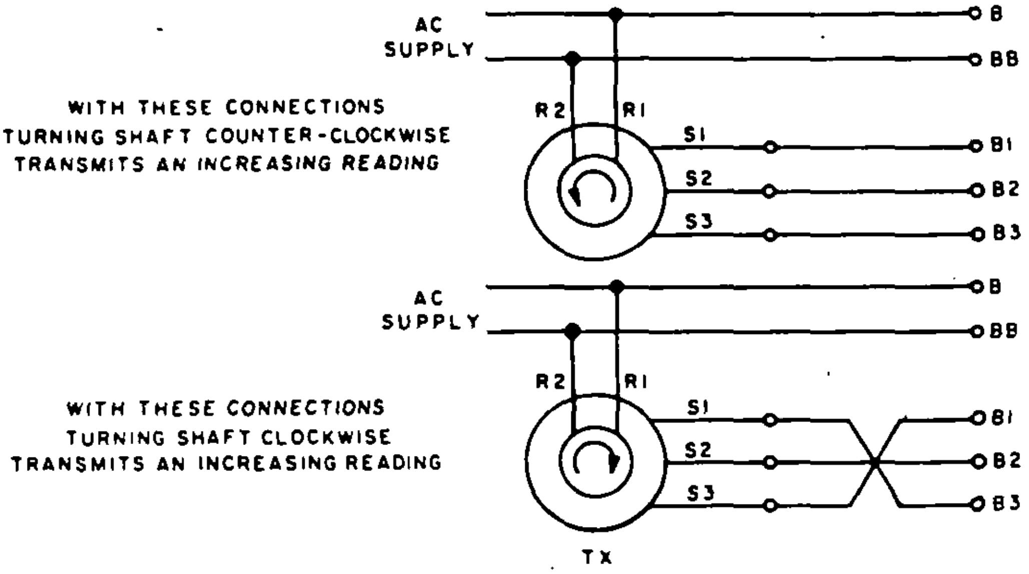


FIGURE 123. Standard transmitter connections.

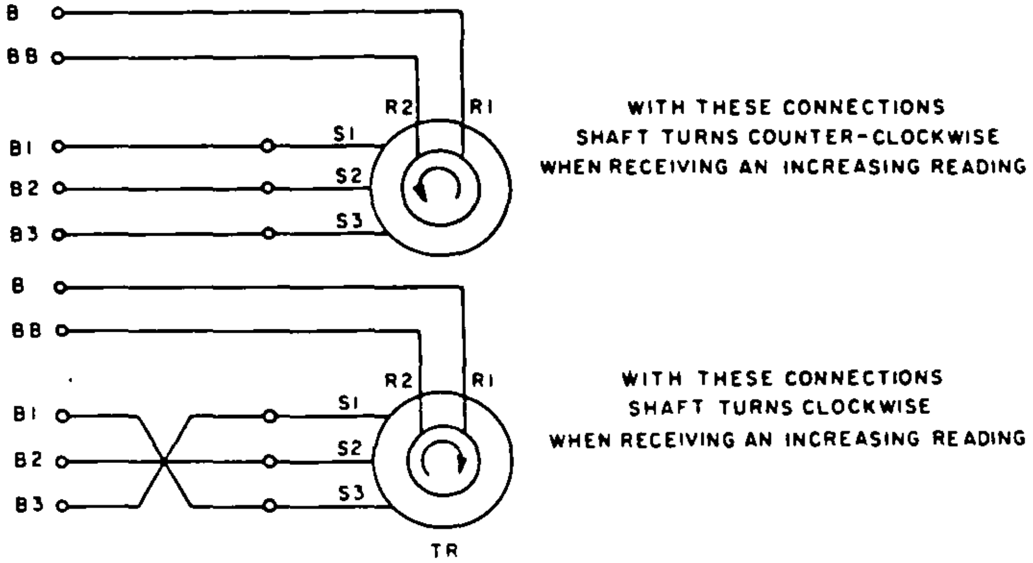


FIGURE 124. Standard receiver connections.

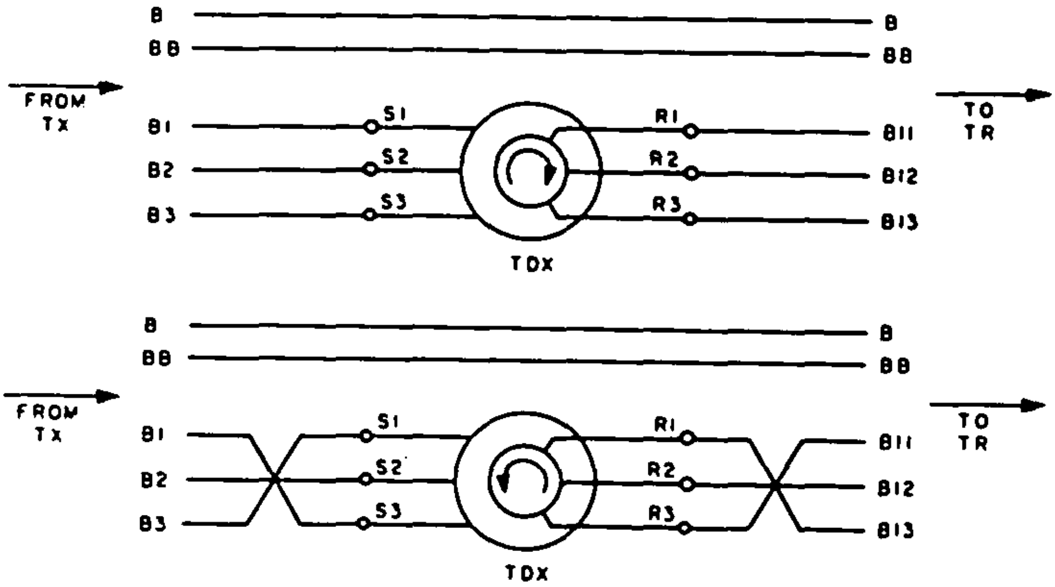


FIGURE 125. Standard connections for differential transmitters.

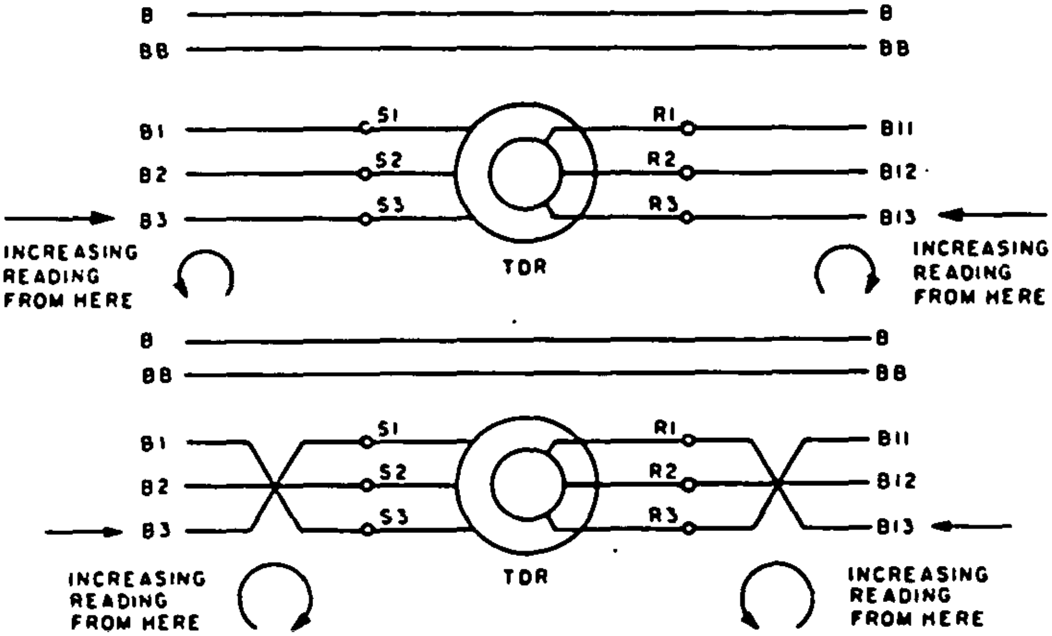


FIGURE 126. Standard connections for differential receivers.

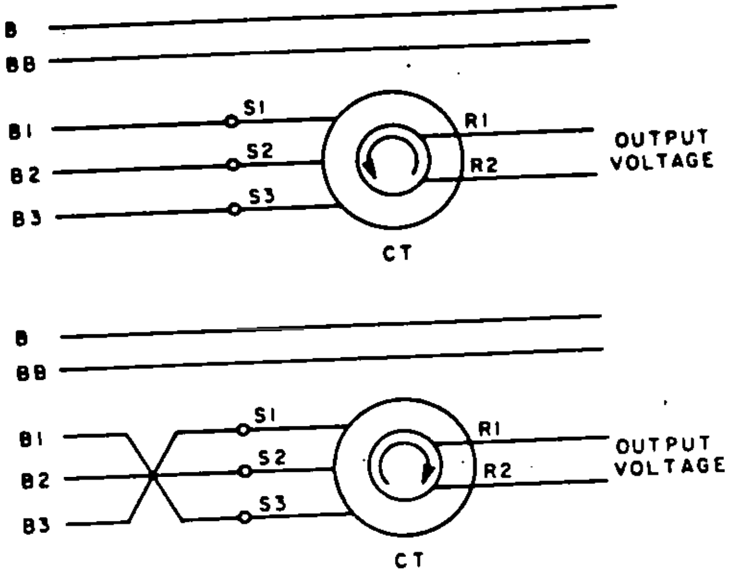


FIGURE 127. Standard connections for control transformers.

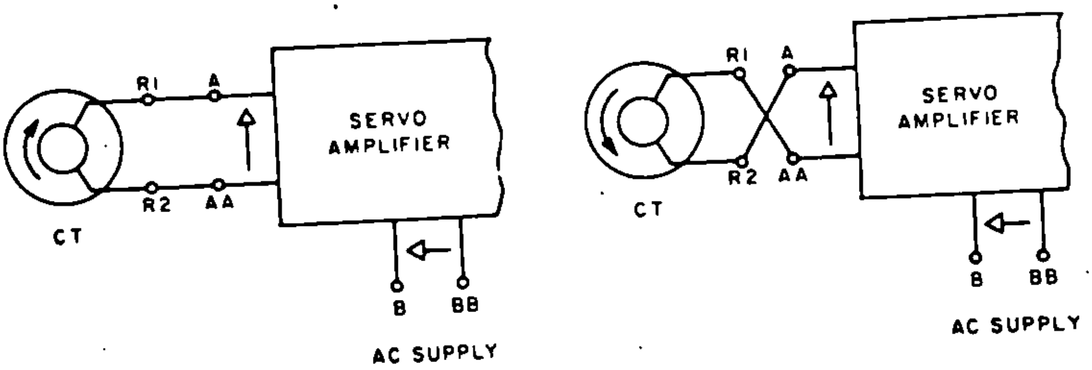


FIGURE 128. Standard connections for control transformers to servo amplifier.

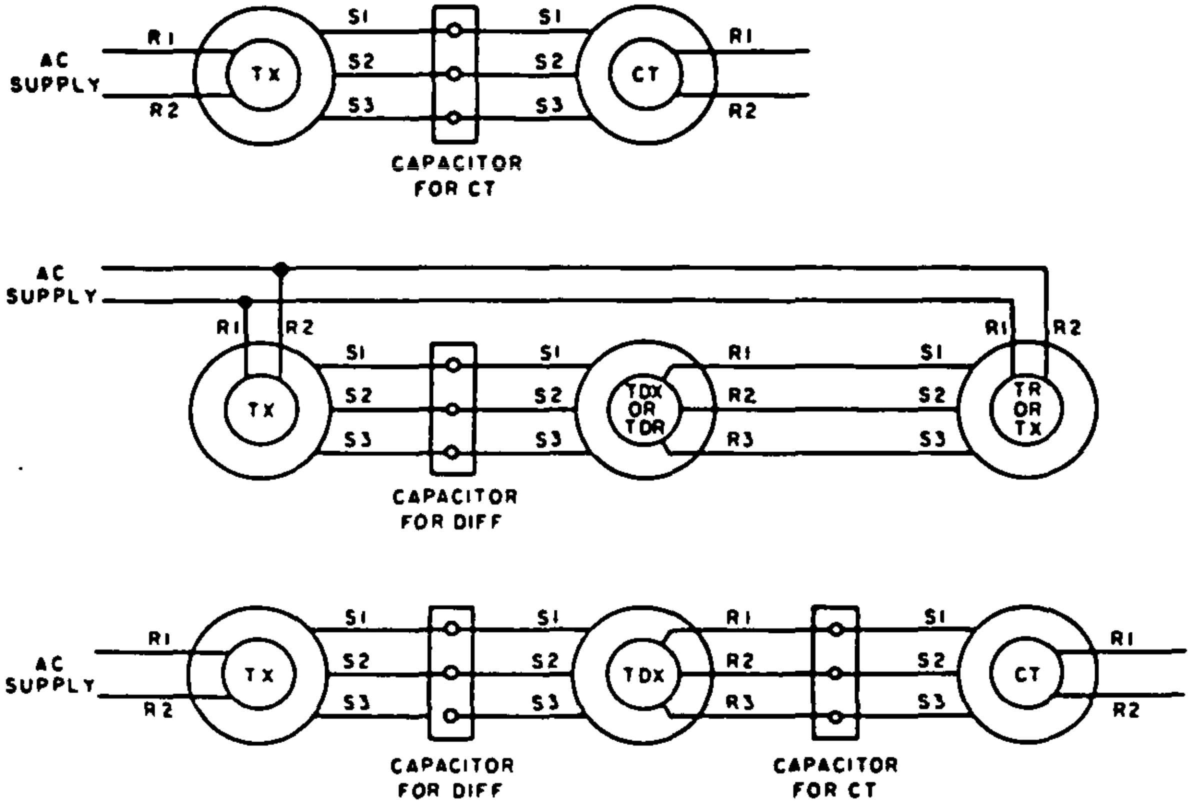


FIGURE 129. Standard connections for synchro capacitors.

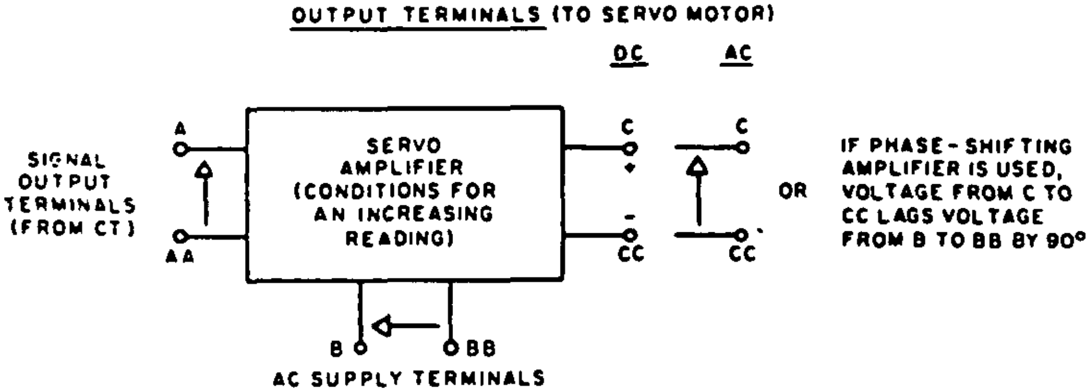

OUTPUT TERMINALS (TO SERVO MOTOR)
DC
AC
SIGNAL OUTPUT TERMINALS (FROM CT)
A
AA
SERVO AMPLIFIER (CONDITIONS FOR AN INCREASING READING)
C
+
-
CC
C
CC
OR
IF PHASE-SHIFTING AMPLIFIER IS USED, VOLTAGE FROM C TO CC LAGS VOLTAGE FROM B TO BB BY 90°
B
BB
AC SUPPLY TERMINALS

FIGURE 130. Standard connections for servo amplifiers.

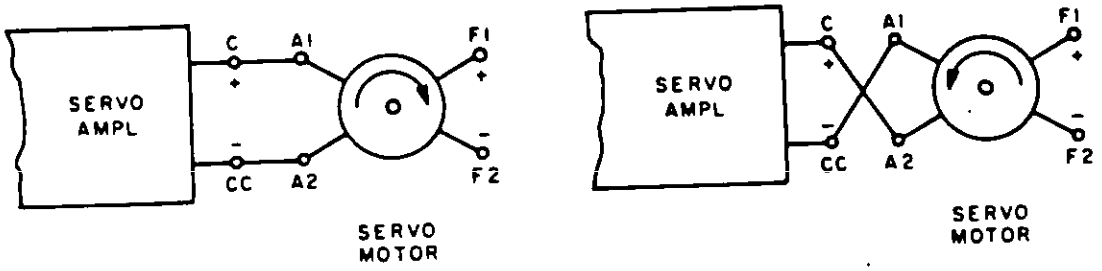


FIGURE 131. Standard connections for shunt field DC servomotor.

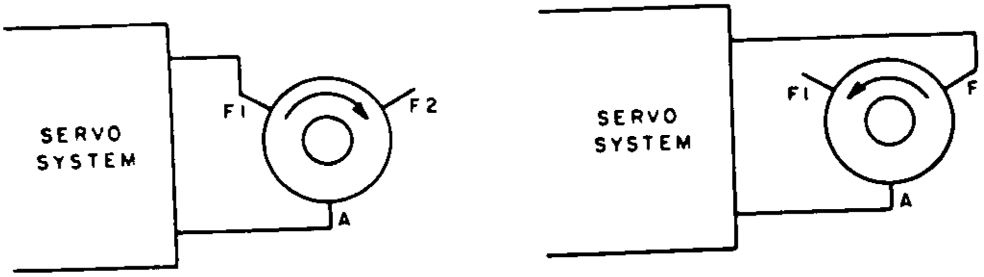
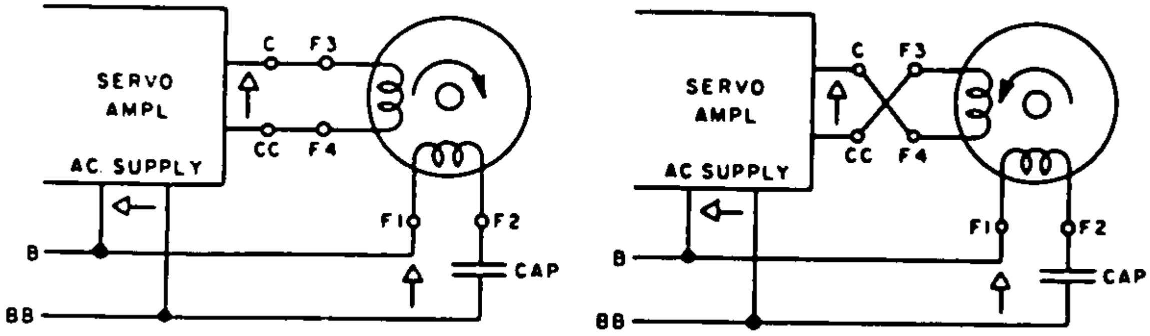


FIGURE 132. Standard connections for split series field, commutator type, AC or DC servomotor.

TWO FIELD INDUCTION TYPE AC SERVO MOTOR WITH CAPACITOR



TWO FIELD INDUCTION TYPE AC SERVO MOTOR WITH 90° PHASE SHIFT IN SERVO AMPLIFIER

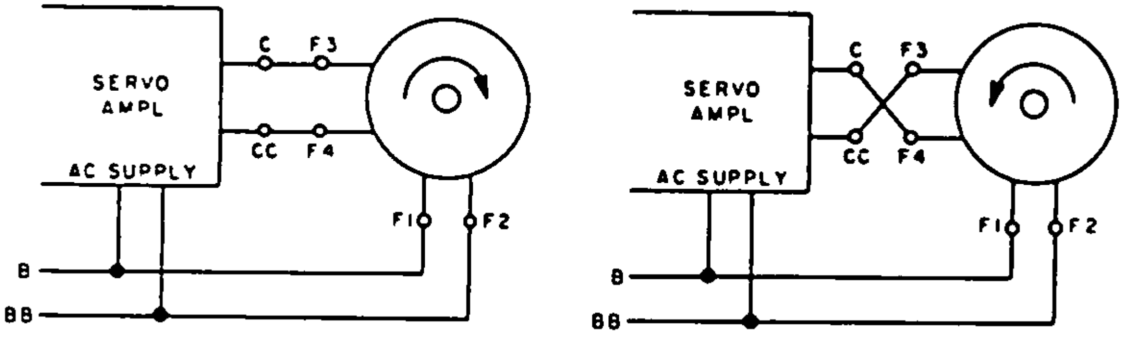


FIGURE 133. Standard connections for two-field induction servomotors.

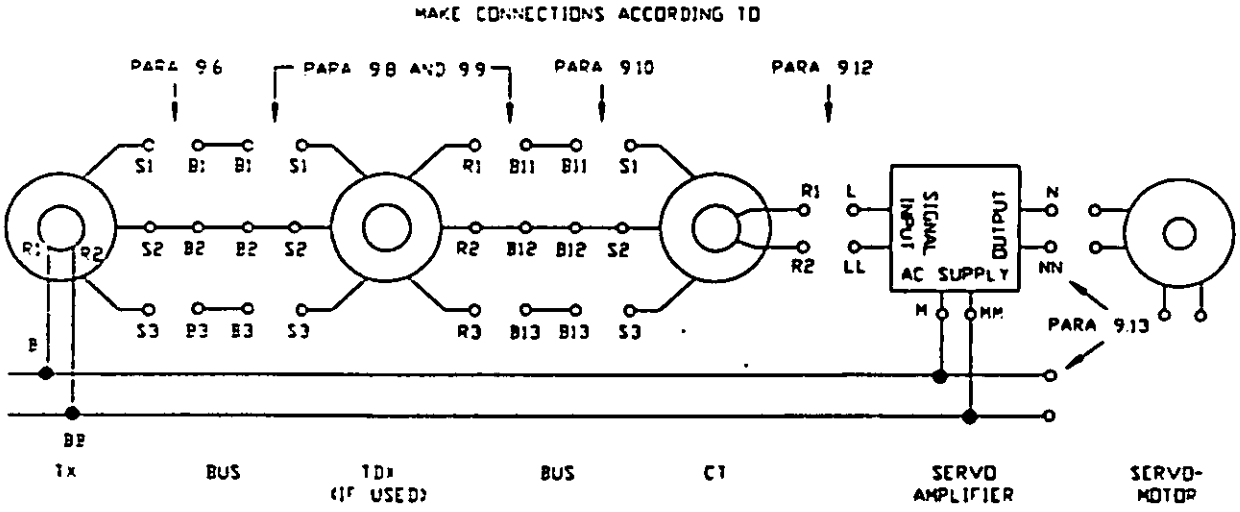


FIGURE 134. Standard connections that apply to a typical servo system.

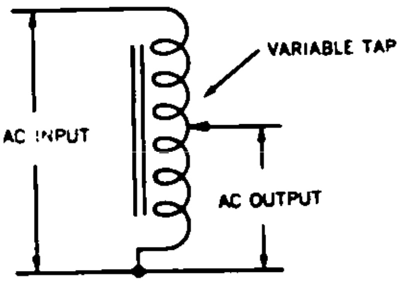


FIGURE 135. Schematic diagram of autotransformer.

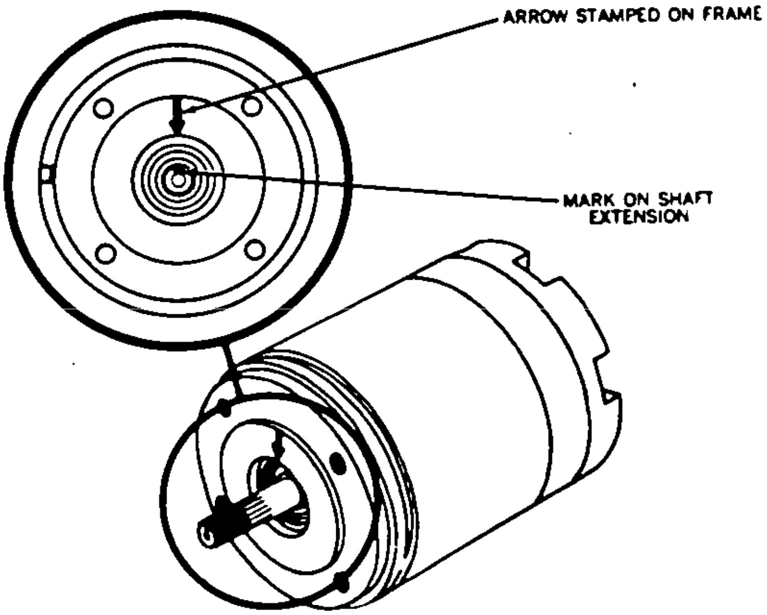


FIGURE 136. Coarse electrical zero markings on synchro units.

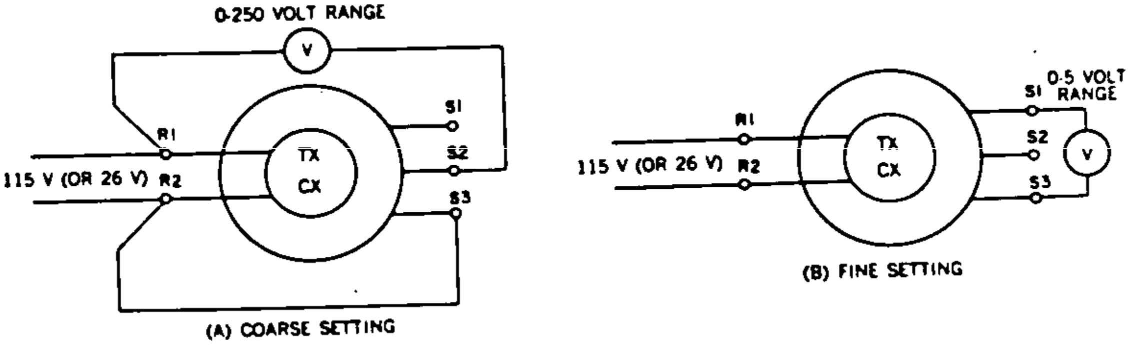


FIGURE 137. Zeroing a TX or CX using a voltmeter.

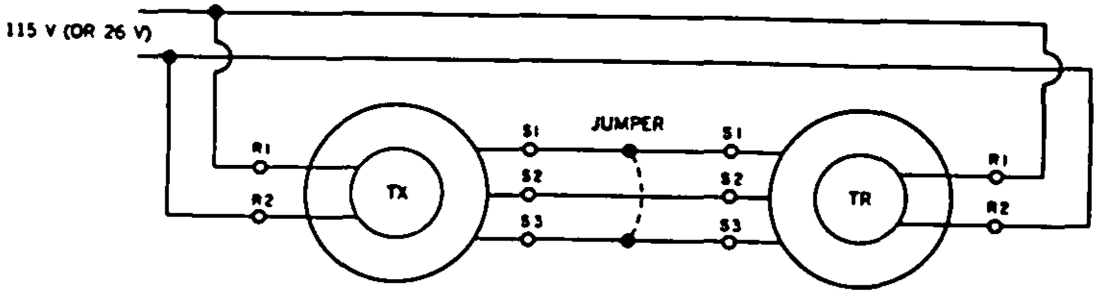
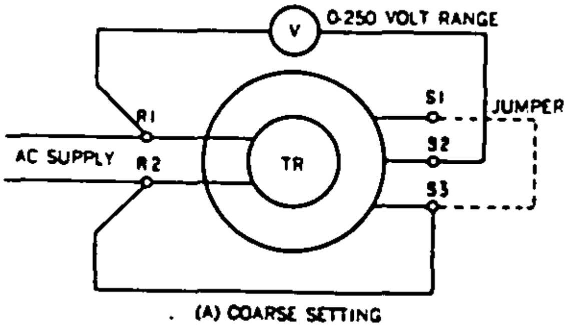


FIGURE 138. Zeroing a TX using a TR.



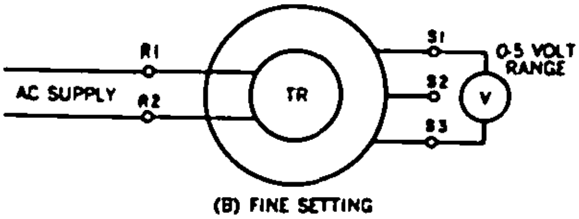


FIGURE 139. Zeroing a TR with a free rotor.

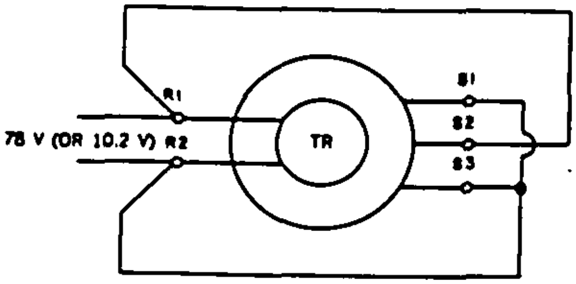


FIGURE 140. Zeroing torque receiver by electrical lock.

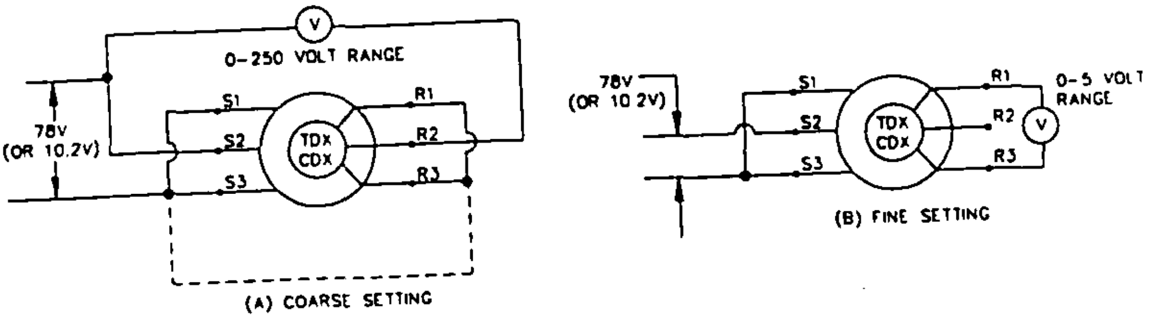


FIGURE 141. Zeroing a differential transmitter using a voltmeter.

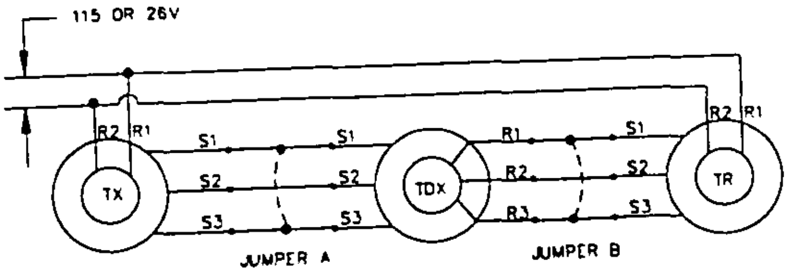


FIGURE 142. Zeroing a TDX using a TX and TR.

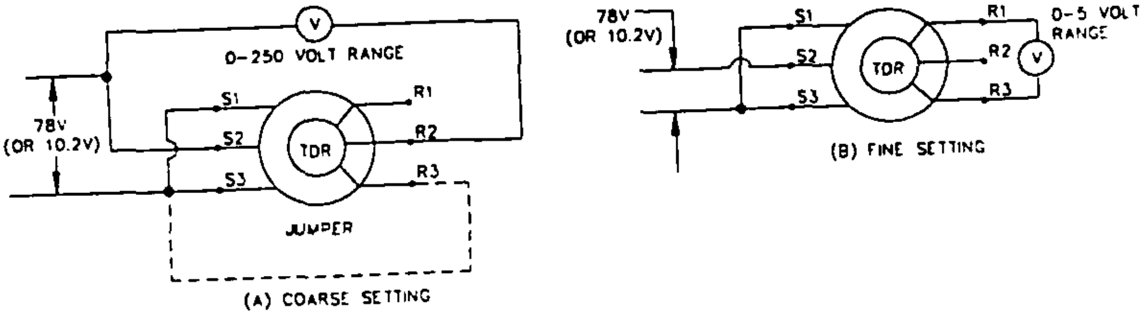


FIGURE 143. Zeroing a TDR with free rotor.

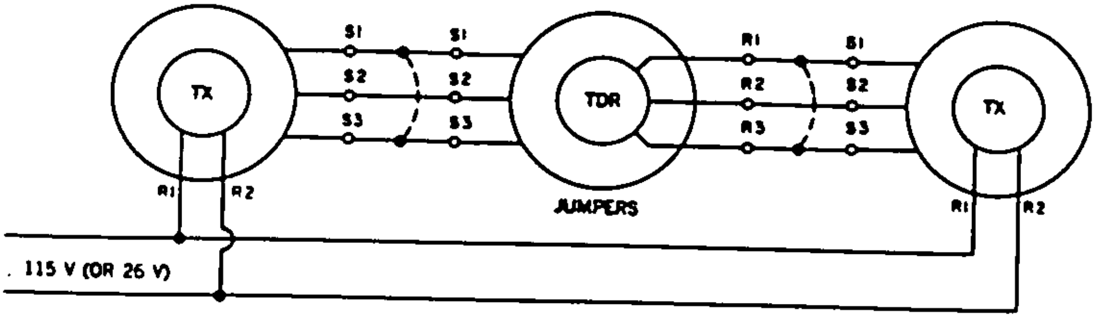
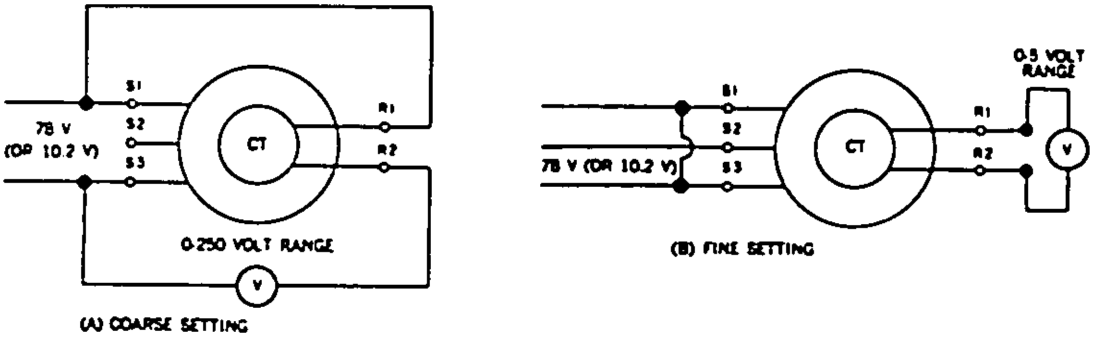


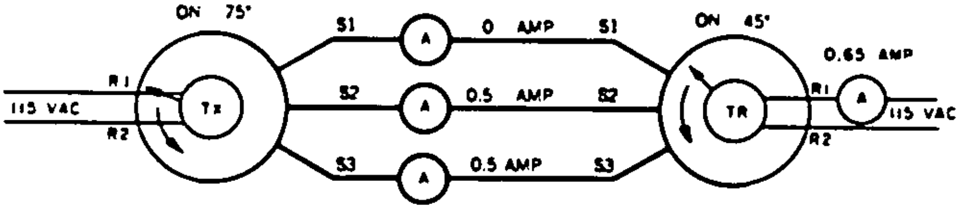
FIGURE 144. Zeroing a TDR using two zeroed TX's.



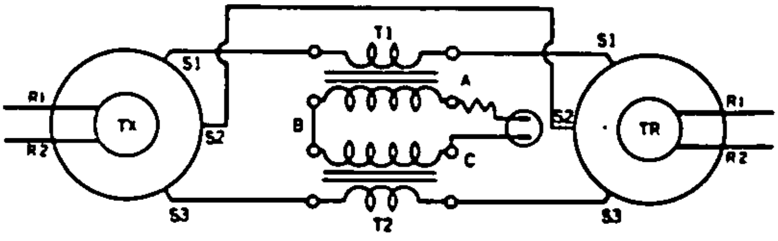
(A) COARSE SETTING

(B) FINE SETTING

FIGURE 145. Zeroing a CT using a voltmeter.



(A) TR LAGS BEHIND TX BY 30°



NEON LAMP LIGHTS WHEN VOLTAGE ACROSS IT EXCEEDS ABOUT 45-50 VOLTS

(B) OVERLOAD INDICATOR ADDED

FIGURE 146. Overload indicator in TX-TR system.

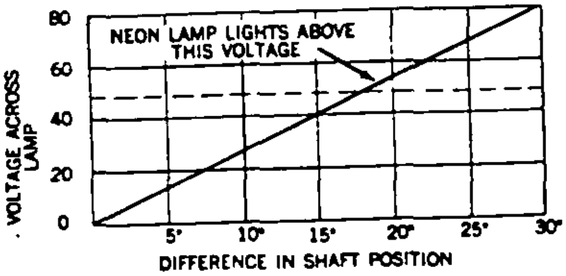


FIGURE 147. Determining when overload indicator will light.

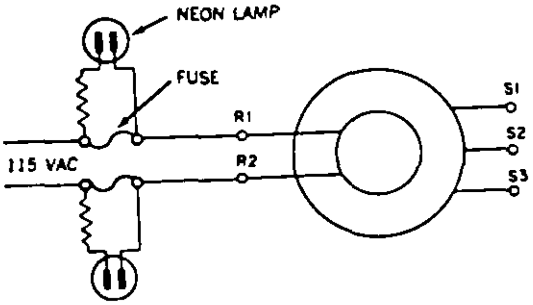


FIGURE 148. Simple blown fuse indicator.

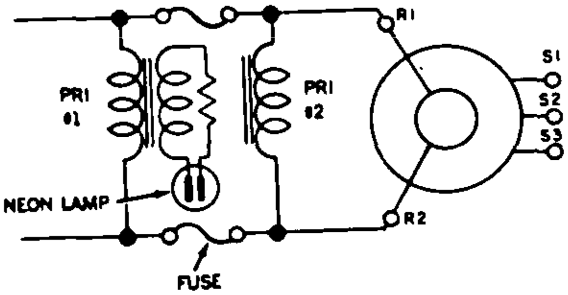


FIGURE 149. Blown fuse indicator requiring only one lamp.

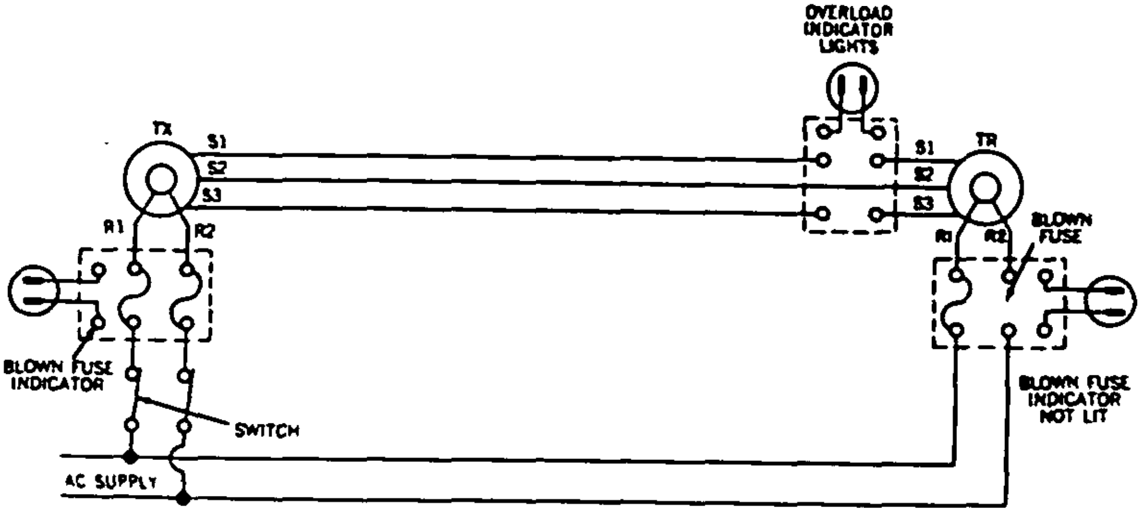


FIGURE 150. Blown fuse lights overload indicator.

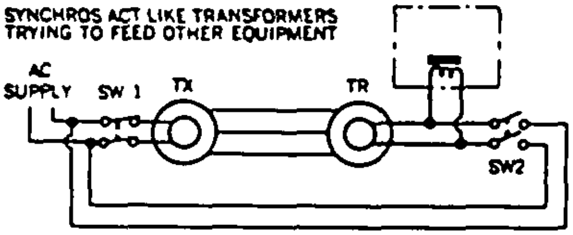

SYNCHROS ACT LIKE TRANSFORMERS TRYING TO FEED OTHER EQUIPMENT
AC SUPPLY
SW 1
TX
TR
SW2

FIGURE 151. Other equipment in parallel with synchros.

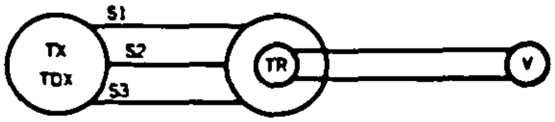


FIGURE 152. Voltage balance check.

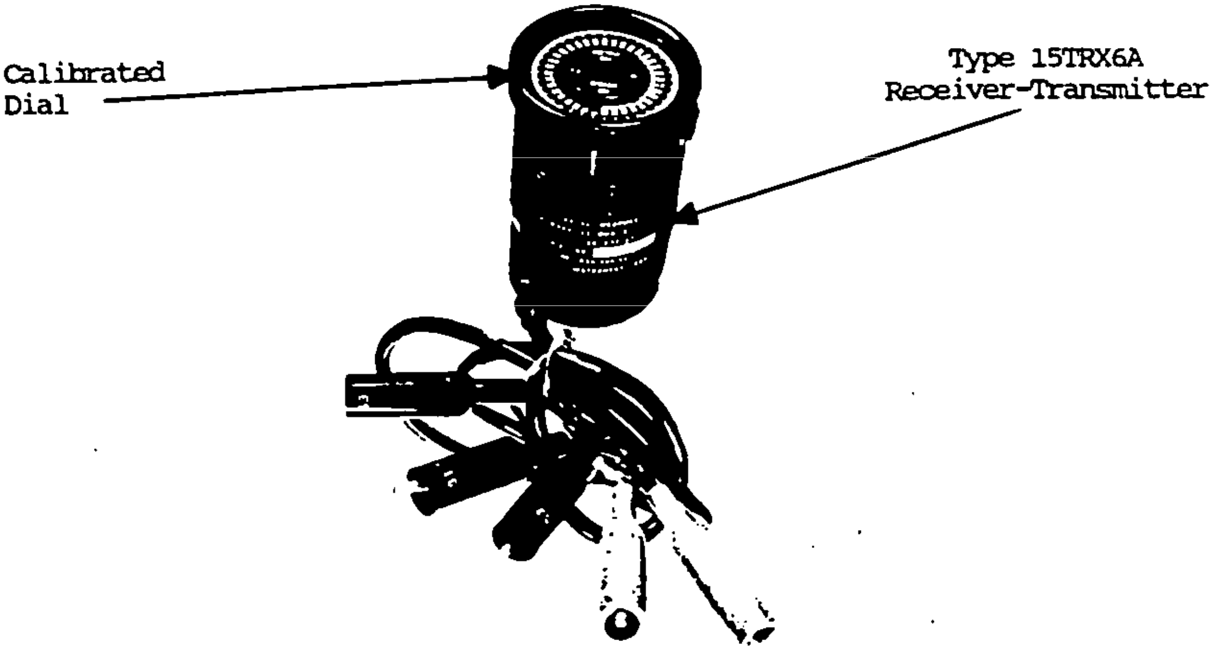


FIGURE 153. 60-hertz Synchro Tester Mk 33 Mod 0.

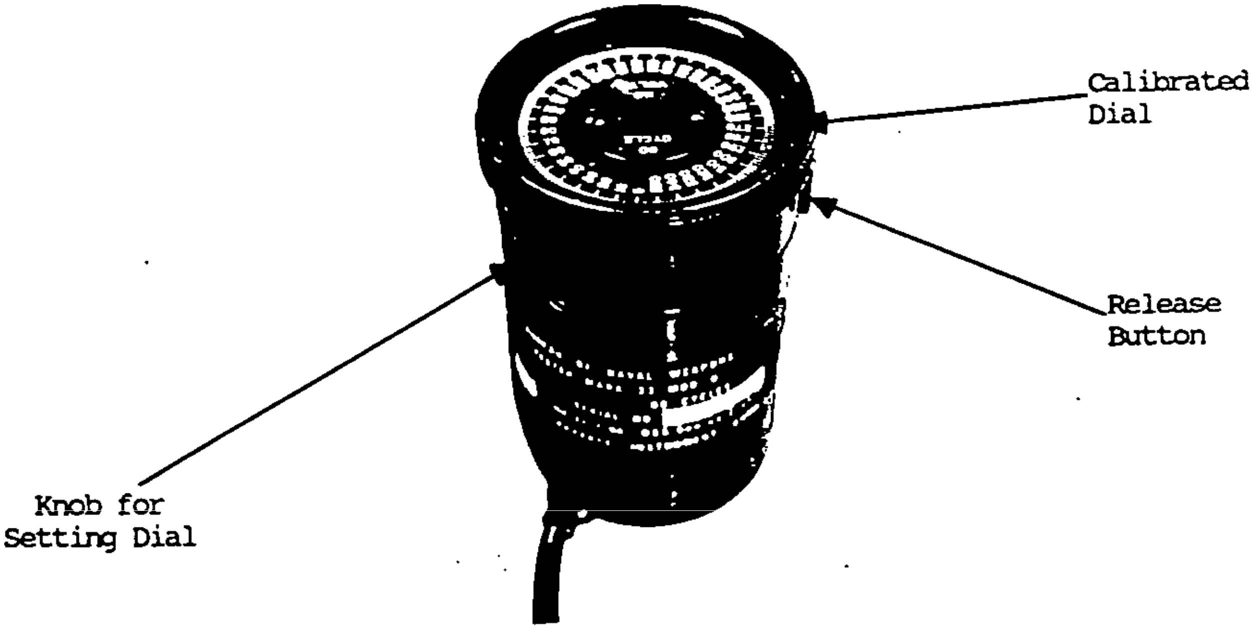


FIGURE 154. Close-up view of dial and index on 60-hertz Synchro Tester Mk 33 Mod 0.

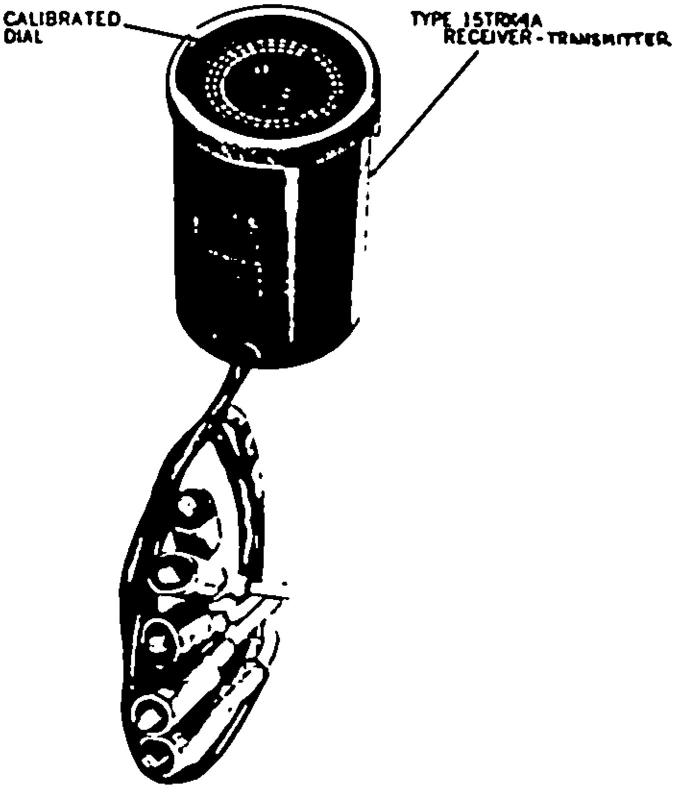


FIGURE 155. 400-hertz Synchro Tester Mk 30 All Mods.

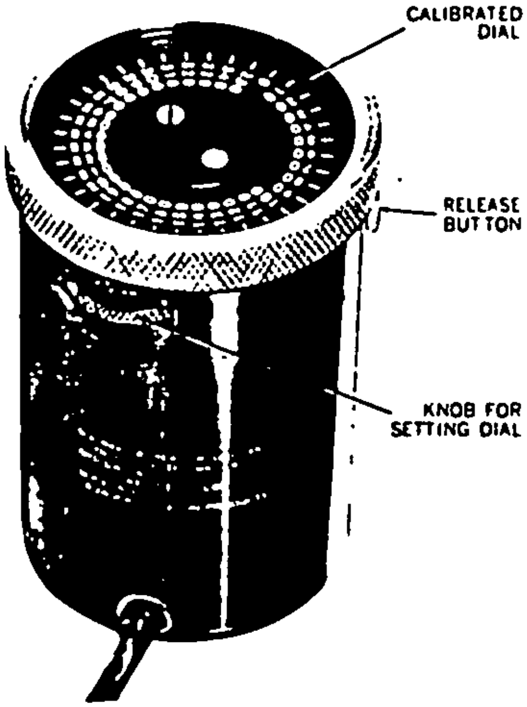


FIGURE 156. Close-up view of dial on 400-hertz Synchro Tester Mk 30 All Mods.

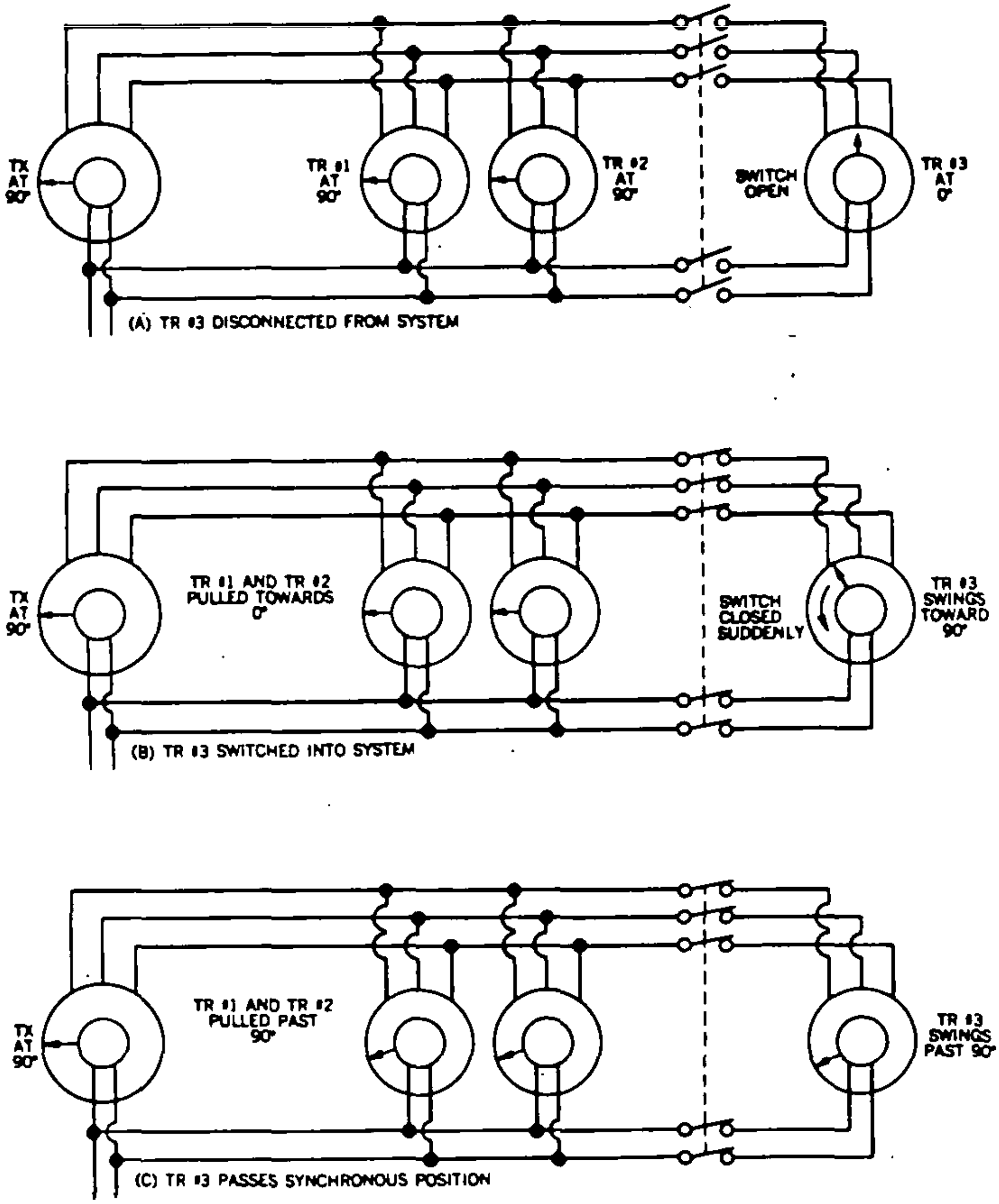

TX AT 90°
TR #1 AT 90°
TR #2 AT 90°
SWITCH OPEN
TR #3 AT 0°
(A) TR #3 DISCONNECTED FROM SYSTEM
TX AT 90°
TR #1 AND TR #2 PULLED TOWARDS 0°
SWITCH CLOSED SUDDENLY
TR #3 SWINGS TOWARD 90°
(B) TR #3 SWITCHED INTO SYSTEM
TX AT 90°
TR #1 AND TR #2 PULLED PAST 90°
TR #3 SWINGS PAST 90°
(C) TR #3 PASSES SYNCHRONOUS POSITION

FIGURE 157. Switching oscillations.

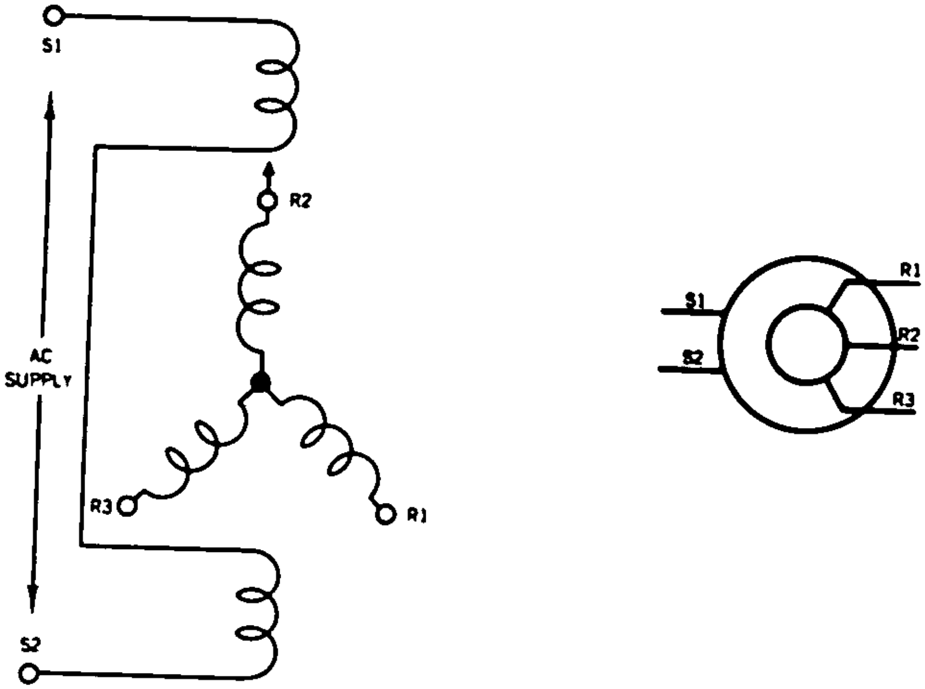
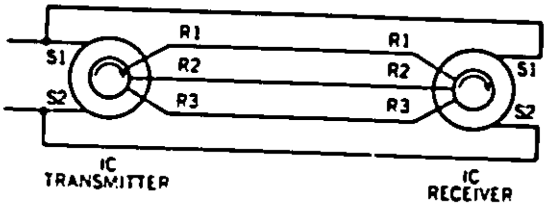
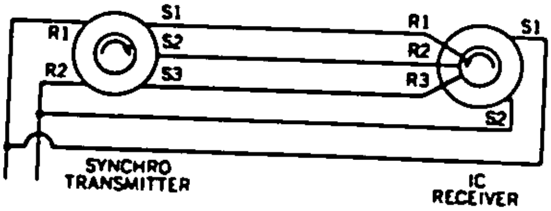


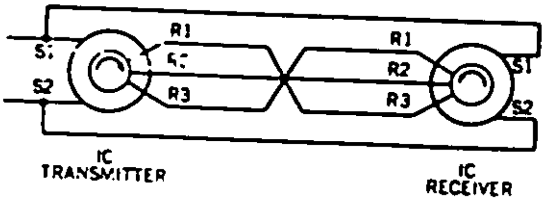
FIGURE 158. IC unit schematic diagrams.



(A) IC TRANSMITTER AND IC RECEIVER IN PARALLEL-SHAFTS ROTATE IN SAME DIRECTION

(B) SYNCHRO TRANSMITTER AND IC RECEIVER IN PARALLEL-SHAFTS ROTATE IN OPPOSITE DIRECTIONS





(C) IC TRANSMITTER AND IC RECEIVER WITH R1 AND R3 LEADS INTERCHANGED-SHAFTS ROTATE IN OPPOSITE DIRECTIONS

FIGURE 159. IC unit shaft rotation.

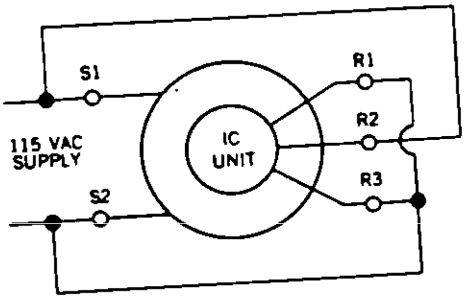


FIGURE 160. Zeroing an IC unit.

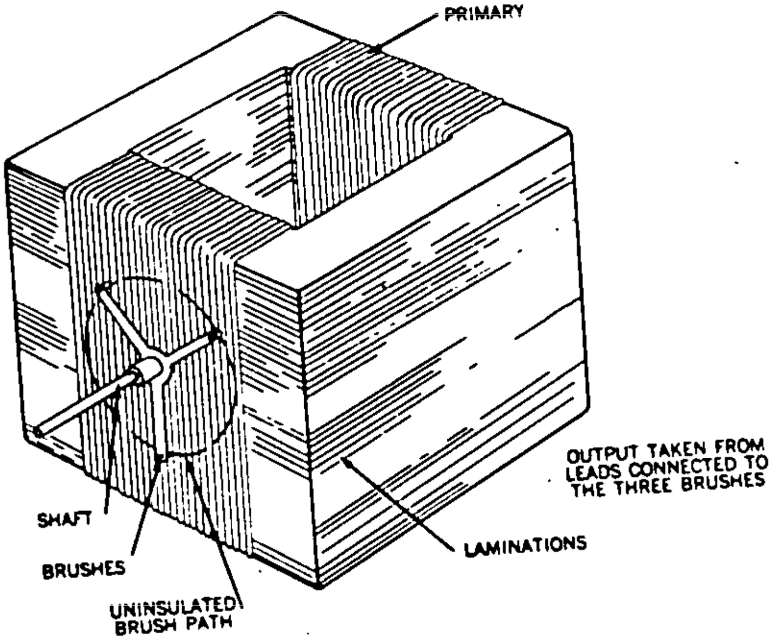


FIGURE 161. Commutator transmitter.

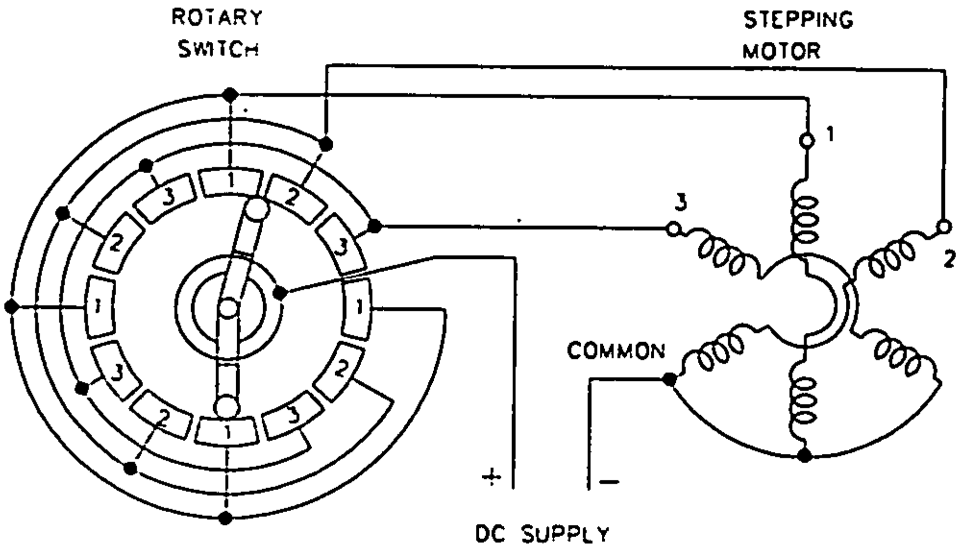


FIGURE 162. Stepping motor system.

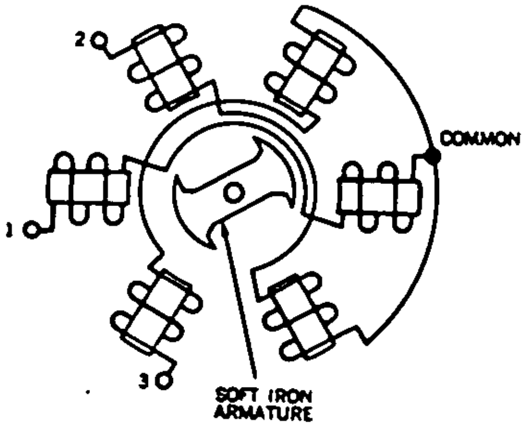
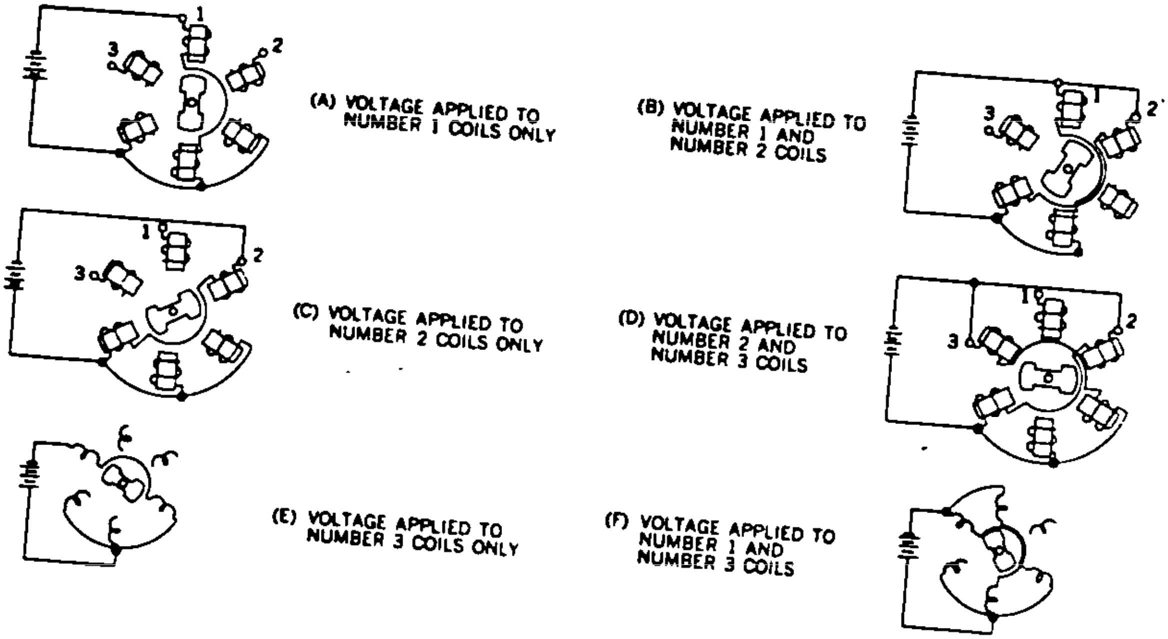


FIGURE 163. Stepping motor.



(A) VOLTAGE APPLIED TO NUMBER 1 COILS ONLY

(B) VOLTAGE APPLIED TO NUMBER 1 AND NUMBER 2 COILS

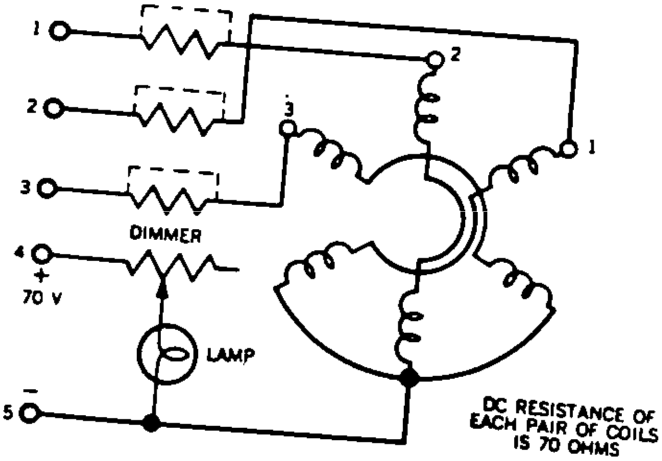
(C) VOLTAGE APPLIED TO NUMBER 2 COILS ONLY

(D) VOLTAGE APPLIED TO NUMBER 2 AND NUMBER 3 COILS

(E) VOLTAGE APPLIED TO NUMBER 3 COILS ONLY

(F) VOLTAGE APPLIED TO NUMBER 1 AND NUMBER 3 COILS

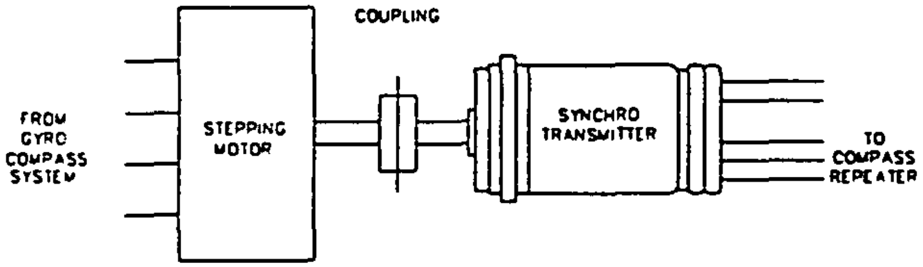
FIGURE 164. Stepping motor in various positions.



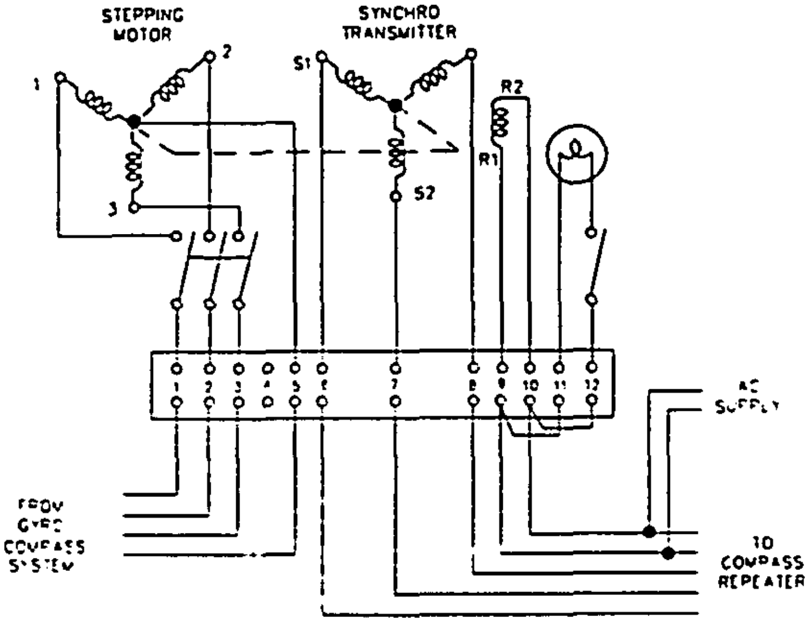
THE THREE RESISTORS (180 OHMS EACH) ARE SHORTED OUT AS SHOWN BY THE DOTTED LINE FOR 20-VOLT OPERATION OF MOTOR

DC RESISTANCE OF EACH PAIR OF COILS IS 70 OHMS

FIGURE 165. Typical stepping motor showing terminals.



(A) PHYSICAL ARRANGEMENT



(B) ELECTRICAL ARRANGEMENT

FIGURE 166. Stepping motor to synchro converter.

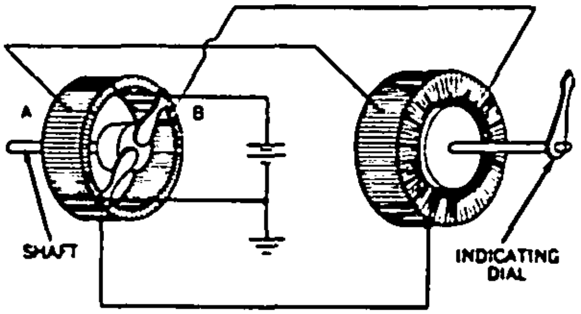


FIGURE 167. DC position indicator.

INDEX

TITLE	PARAGRAPH	PAGE
AC		
Effective value	1.4.4.1	5
Voltmeter calibration	1.4.4.1	5
Acceleration figure of merit	6.4.3	53
Adapter assemblies	8.2.3	56
Addition		
Differential receiver	6.2.2.5.2	45
Differential transmitter	6.2.2.4	44
Angle reader train dials	4.8.2	14
Angular adjustment tools	8.3.1	57
Angular displacement	3.2.1.4	10
Assembly of units	4.5	12
Basic principles	1.4	2
Checking standard voltages	11.3.7	72
Clamping disc assembly	8.2.2	56
Classification	1.3	1
Commutator transmitter	12.3	80
Comparison of 60-cycle and 400-cycle units	4.12	16
Control		
Closed-cycle	3.4.2	10
Continuous	3.4.3	11
Open-cycle	3.4.1	10
Systems	1.3.2.1	1
Transformer	3.1.1.7, 6.3.1	9, 47
Characteristics and usage	4.10	15
Connections, standard	9.10	61
Electrical zero	10.2.3	64
Error	6.3.2.2	50
Null voltage	4.13.9.1	20
Operation with synchro transmitter	6.3.1.2	48
Output	6.3	47
Voltage gradient	4.13.10	20
Zeroing	10.2.3	64
Converter, stepping motor to synchro	12.4.3	81
Damping constant	6.4.3	53
DC position indicator	12.5	81
Definitions	3.1	8
Deviation, servo	3.4.4	11
Dials, mounting	8.6	59
Diamagnetic	1.4.1.3	2
Differential units	6.2.2.1	41
Definition	4.9	14
Electrical zero	10.2.2	64

TITLE	PARAGRAPH	PAGE
Differential units (Continued)		
Receiver	4.9.2	15
Connections, standard	9.9	61
Zeroing	10.3.7, 10.3.8, 10.3.9, 10.3.10, 10.3.11	67, 67 68, 68 68
Rules for connecting	6.2.3	46
Transformer action	4.9.3	15
Transmitter	4.9.1, 6.2.2.3 6.2.2.4	15, 42 44
Connections, standard	9.8	61
Zeroing	10.3.9, 10.3.10	68
With rotatable stator	4.11	16
Direction of rotation	3.2.1.3	10
Double receiver (see Receiver, double)	4.8	14
Drive washers	8.2.6	57
Dumbbell rotor	4.2.1	11
Pre-standard synchros	7.	54
Definition	7.2.1.2	56
Designation code.	7.1, 7.1.2	54, 55
Mounting gears and dials.	8.6.2	59
Mounting methods.	8.5	58
Bearing	8.5.3	59
Flange.	8.5.1	58
Nozzle.	8.5.2	59
Effective value	1.4.4.1	5
Electrical error and static accuracy.	4.13.5	19
Electrical zero	3.2.1.5	10
Conditions.	10.2	63
Control transformer	10.2.3	64
Differentials	10.2.2	64
Mechanical reference points	10.1.1	62
Need for.	10.1	62
Procedures.	10.3	64
Summary	10.4	69
By electrical lock.	10.3.5	66
General	10.3	64
Using an AC voltmeter	10.3.10	68
Using a receiver and torque transmitter	10.3.7	67
Using a receiver or synchro tester	10.3.2	65
Using two zeroed transmitters	10.3.9	68
Using voltmeter	10.3.1, 10.3.6, 10.3.10	64,66, 68
Using 115 volts	10.3.11	68
With a free rotor	10.3.3, 10.3.8,	65, 67,
With rotor not free to turn	10.3.4	66
Transmitters and receivers	10.2.1	63

INDEX - Continued

TITLE	PARAGRAPH	PAGE
Electromagnetism	1.4.2	3
Error		
Control synchro systems	6.3.2	50
Control transformers	6.3.2.2	50
Electrical	6.3.2.1	50
Receiver	4.1.3.6 6.3.2.3.1	19 51
Signal	3.4.5	11
Speed	6.3.2.2.2	51
Static	6.4.3	53
Static under load	6.4.3	53
Use of torque and control units in same system	6.3.2.3	51
Figure of merit		
Acceleration	6.4.3	54
Velocity	6.4.3	53
Follow-the-pointer dials	4.8.1	14
Gears, mounting	8.6	59
General synchro construction and characteristics	4.	11
"H" rotor	4.2.1	11
Government documents	2.1	7
Government specifications and standards	2.3.1	8
Hardware for new standard units	8.2	56
Hardware, tools, and mounting methods	8.	56
IC (interior communication) units	12.2	74
Construction	12.2.1	74
Interchangeability with synchros	12.2.6	78
Maintenance	12.2.5	78
Operation	12.2.2	75
Unit troubles	12.2.4	77
Zeroing	12.2.3	75
Increasing reading	3.2.1.6, 9.2	10, 60
Indicators, trouble (see Trouble indicators)	11.3.4	70
Inertia damper	4.7.1	13
Instrument servo	3.4.6	11
Lamination		
Skew	4.4	12
Stacking	4.4	12
Load capacity	4.13.2.2	18
Load limits for MIL-S-20708 synchros		
In control systems	5.3	32
In mixed systems	5.2	30
In torque systems	5.1	25
Magnet types	1.4.1.1	2
Magnetic attraction and repulsion	1.4.1.3	2
Magnetic fields	1.4.1.4, 6.2.2.2	3, 41
Magnetism	1.4.1	2

INDEX - Continued

TITLE	PARAGRAPH	PAGE
Maintenance		
IC units	12.2.5	78
Synchro systems	11.2	69
Military synchro types	7.	54
Designation codes	7.1	54
Military specifications and standards for synchros	7.2	55
Minimum voltage (null) and fundamental component	4.13.9	19
Molecular arrangement	1.4.1.5	3
Mounting clamp assembly	8.2.1	56
Mounting gears and dials	8.6	59
Double receiver	8.6.3	59
Pre-standard synchros	8.6.2	59
New standard synchros	8.6.1	59
Mounting synchros (see synchro, mounting)	8.4, 8.5	57, 58
New standard synchros		
Defined	7.1	54
Designation code	7.1	54
Mounting gears and dials	8.6	59
Mounting methods		
Using adapter assembly, from shaft end	8.4.3	58
Using adapter assembly, from terminal board end	8.4.4	58
Using clamping disc assembly	8.4.2	58
Using #4-48 screws	8.4.1	57
Using three mounting clamp assemblies	8.4.5	58
Using zeroing ring	8.4.6	58
Size	7.1.1	54
Null (see Minimum voltage)	4.13.9	19
Operating		
Frequency	1.4.5.3	6
Speeds	4.13.8	19
Temperature	4.13.4	19
Voltages	4.13.3	19
Order of precedence	2.2	8
Oscillation	11.4	73
Paramagnetic	1.4.1.3	2
Permeability	1.4.1.3	2
Phase relationships	1.4.4	5
Poles	1.4.1.2	2
Positioning a permanent magnet with electromagnets	1.4.3	3
Using two electromagnets	1.4.3.1	4
Using three electromagnets	1.4.3.2	4
Using AC instead of DC	1.4.3.3	4
Position of coils	1.4.5.2	6
Position servo	6.4.2.2	52
Power	4.15.1.2	22
Power servo	3.4.6	11

INDEX - Continued

TITLE	PARAGRAPH	PAGE
Receiver		
Connections, standard	9.7	61
Construction and characteristics	4.7	13
Stator voltages required to position rotor	4.7.2	14
Differential	6.2.2.5	45
Electrical zero	10.2.1	63
Error	4.13.6	19
Torque	3.1.1.5,	9,
Torque differential	3.1.1.6,	9,
Zeroing	10.3.4, 10.3.5, 10.3.6	66
Receiver, double	4.8	14
Dial mounting	8.6.3	59
Referenced documents	2.	7
Reversing direction of receiver rotation	6.2.1.3	39
Right-hand rule		
Coil	1.4.2	3
Conductor	1.4.2	3
Rotor		
Angle	3.2.1.2	10
Construction	4.2	11
Salient Pole rotor	4.2.1	11
Drum or wound rotors	4.2.2	12
Currents	6.2.1.5	40
Defined	4.1	11
H-type	4.2.1	11
Position	3.2.1.1	10
Rotor movement	4.7.1	13
Stator voltages required to position	4.7.2	14
Schematic symbols, synchros	1.3.1.1	1
Scope	1.	1
Servo (see Servo system)	6.4	51
Servo amplifiers, standard connections for	9.12	61
Servomechanism (see Servo system)	6.4	51
Servomotors, standard connections for	9.13, 9.14	62
Servo system	3.3	10
Classification	6.4.2	52
Ratings	6.4.3	53
Requirements of	6.4.1	52
Terminology	3.4	10
Using synchros	6.4	51
Servtorqs	4.16	24
Shaft nuts	8.2.5	57
Similar devices	12.	74
Slip rings	4.2, 4.2.2 4.3.1	11, 12 12
Slot-lock	4.4	12

INDEX - Continued

TITLE	PARAGRAPH	PAGE
Socket wrench assembly	8.3.2	57
Solenoid	1.4.2	3
Source of documents	2.3	8
Special synchros (servtorqs)	4.16	24
Specifications and standards	2.1.1	7
Speed of synchro units and systems	4.14	20
Data transmission speeds	4.14.1	20
Determining speed to use	4.14.4	21
Summary	4.14.3	21
System speeds	4.14.2	21
Standard connections for synchros	9.	60
Need for	9.1	60
Stator		
Construction	4.3	12
Currents	6.2.1.4	39
Defined	4.1	11
Rotatable	4.3.1, 4.11	12, 16
Slip rings and brushes	4.3.1	12
Voltages in a CT, relationship to the resultant magnetic field	6.3.1.1	48
Voltages required to position rotor	4.7.2	14
Voltages, terminal-to-terminal	4.6.1	13
Stepping motor system	12.4	80
Zeroing to synchro converter	12.4.4	81
Subtraction		
Differential receiver	6.2.2.5.1	45
Differential transmitter	6.2.2.3	42
Symbols, schematic	1.3.1.1	1
Synchro		
Assembly	4.5	12
Capacitors	4.15	22
AC current drawn by a coil	4.15.1	22
Characteristics of Navy standard synchro capacitors	4.15.9	24
Connections, standard	9.11	61
Effect of a capacitor on coil current	4.15.2	22
General notes concerning synchro capacitors	4.15.5	24
Synchro capacitor boxes	4.15.8	24
Synchro capacitor location in synchro system	4.15.6	24
Use of capacitors to reduce line current of a transmitter or receiver	4.15.7	24
Use of capacitors with a control transformer	4.15.3	22
Use of capacitors with a synchro differential	4.15.4	23
Characteristics	4.13	16
Classification	1.3	1
Comparison of 60-hertz and 400-hertz units	4.12	16
Connections	9.	60

INDEX - Continued

TITLE	PARAGRAPH	PAGE
Synchro (Continued)		
Construction	4.	11
Definition	3.1.1	8
Load limits (see Control and Torque)	5.	25
Mounting gears and dials	8.6	59
Pre-standard	8.6.2	59
Newer standard	8.6.1	59
Mounting methods, earlier	8.5	58
Bearing	8.5.3	59
Flange	8.5.1	58
Nozzle	8.5.2	58
Mounting methods, newer	8.4	57
Using adapter assembly from shaft end	8.4.3	58
Using adapter assembly from terminal board end	8.4.4	58
Using clamping disc assembly	8.4.2	58
Using 4-40 screws	8.4.1	57
Using three mounting clamp assemblies	8.4.5	58
Using zeroing ring	8.4.6	58
Terminology	3.2	10
Zeroing	10.	62
Synchro systems	1.3.2, 3.1.2 6.1	1, 9 37
Control	3.1.2.2, 6.3	9, 47
Handling	11.1	69
Maintenance	11.2	69
Servo	6.4	51
Torque	6.2	37
Accuracy	6.2.4	46
Transmitter and receiver	6.2.1	37
Rotors in corresponding positions	6.2.1.1	37
Rotors not in corresponding positions	6.2.1.2	38
Reversing direction of receiver rotation	6.2.1.3	39
Troubleshooting	11.3	69
Checking standard voltages	11.3.7	72
Existing installations	11.3.3	70
General	11.3.1	69
New installations	11.3.2	69
Symptoms and causes	11.3.5	71
Trouble from other equipment	11.3.6	72
Trouble indicators	11.3.4	70
Use of 60-hertz tester	11.3.9	73
Voltage balance check	11.3.8	72
Two-speed	9.4	60
Synchro tester, Mk 2 All Mods	11.3.9	73
Synchronizing time	4.13.7	19
Synchros in action	6.	37
Three-phase device	1.4.4	5
Tools for newer standard synchros	8.3	57

INDEX - Continued

TITLE — PARAGRAPH — PAGE

- Torque
  - Definition . . . 4.13.1 16
  - Gradient . . . 4.13.1.1 16
    - Effect on accuracy . . . 4.13.1.6 17
    - Actual . . . 4.13.1.3 17
    - Pull-out force . . . 4.13.1.4 17
    - Stator force . . . 4.13.1.5 17
    - Unit . . . 4.13.1.1 16
  - Load limits . . . 5.1 25
  - Oscillations and spinning in torque systems . . . 11.4 73
  - Transmitter load capacities . . . 4.13.2 17
- Transformation ratio . . . 1.4.5.1 6
- Transformer
  - Action in differential units . . . 4.9.3 15
  - Control (see Control transformer) . . . 3.1.1.7 9
  - Definition . . . 1.4.5 5
  - Differential or control transformer connected to a transmitter . . . 4.15.1.1 22
  - Losses . . . 1.4.5.1 6
  - Physical size . . . 1.4.5.3 6
- Transformer theory . . . 1.4.5 5
  - Operating frequency . . . 1.4.5.3 6
  - Physical position of the coils . . . 1.4.5.2 6
  - Transformation ratio and applied voltage . . . 1.4.5.1 6
- Transmitter
  - Commutator . . . 12.3 80
  - Connections, standard . . . 9.6 61
  - Construction and characteristics . . . 4.6 13
    - Terminal-to-terminal stator voltages . . . 4.6.1 13
  - Control . . . 3.1.1.2 9
  - Control differential . . . 3.1.1.4 9
  - Electrical zero . . . 10.2.1 63
  - Receiver . . . 3.1.1.6 9
  - Torque . . . 3.1.1.1 8
  - Torque differential . . . 3.1.1.3 9
  - Zeroing . . . 10.3.1, 10.3.2, 64,65
    10.3.3 65
- Trouble indicators
  - Blown fuse . . . 11.3.4.2 71
  - Overload . . . 11.3.4.1 70
- Troubleshooting . . . 11.3 69
- Unit assembly . . . 4.5 12
- Units with rotatable stator . . . 4.11 16
- Velocity figure of merit . . . 6.4.3 53
- Velocity servo . . . 6.4.3 53
- Voltage balance check . . . 11.3.8 72
- Voltage gradient, control transformer . . . 4.13.10 20
- Voltages, standard . . . 9.5 61
- Wire designations, standard . . . 9.3 60

INDEX - Continued

TITLE	PARAGRAPH	PAGE
Y-connected windings.	4.2.2	12
Zeroing ring	8.2.4	56

Custodians:
  Air Force - 85
  Army - AR
  Navy - AS

Preparing Activity:
  Navy - AS

Review Activities:
  Air Force - 99, 17
  Army - AV
  Navy - EC, SH, OS
  DLA - ES

User Activities:
  Air Force - 19
  Army - AT,
  Navy - CG, MC

(Project 5990-0401)

*U.S. GOVERNMENT PRINTING OFFICE: 1991--504-034/50243

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
2. The submitter of this form must complete blocks 4, 5, 6, and 7.
3. The preparing activity must provide a reply within 30 days from receipt of the form.

NOTE: This form may not be used to request copies of documents, nor to request waivers, or clarification of requirements on current contracts. Comments submitted on this form do not constitute or imply authorization to waive any portion of the referenced document(s) or to amend contractual requirements.

I RECOMMEND A CHANGE:	1. DOCUMENT NUMBER MIL-HDBK-225A	2. DOCUMENT DATE (YYMMDD) 25 MARCH 1991

3. DOCUMENT TITLE SYNCHROS, DESCRIPION AND OPERATION

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME *(Last, First, Middle Initial)*

b. ORGANIZATION

c. ADDRESS *(Include Zip Code)*

d. TELEPHONE *(Include Area Code)*
(1) Commercial
(2) AUTOVON
(if applicable)

7. DATE SUBMITTED
(YYMMDD)

8. PREPARING ACTIVITY

a. NAME
COMMANDING OFFICER
NAVAL AIR ENGINEERING CENTER

b. TELEPHONE *(Include Area Code)*
(1) Commercial 908-323-2258
(2) AUTOVON 624-2258

c. ADDRESS *(Include Zip Code)*
SESD (CODE 53)
LAKEHURST NJ
08733-5100

IF YOU DO NOT RECEIVE A REPLY WITHIN 45 DAYS, CONTACT:
Defense Quality and Standardization Office
5203 Leesburg Pike, Suite 1403, Falls Church, VA 22041-3466
Telephone (703) 756-2340 AUTOVON 289-2340

DD Form 1426, OCT 89

Previous editions are obsolete.

198/290